"Let's buy some books and get the 'old man' to play school teacher for us"—*See page* 10.

McANDREW'S FLOATING SCHOOL

A STORY FOR MARINE ENGINEERS

BY

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Introduction

In presenting these lectures of "McAndrew" in book form, the author does so in the hope that they may be of benefit to some of that great class of hard workers whose life "below the grating" is but little understood by the public at large. These men are the backbone of modern seafarers, as they bear the heat and burden of the work of sea transportation. Inured from early youth to the hardest physical toil known to man, it is scarcely to be presumed that their early education is such as to fit them for the higher positions in engineering; for example, those held by the licensed engineer officers under whom they serve.

Yet all who come in contact with them know that there is not another class of workers in any branch of industry containing so large a number of young men ambitious to reach higher positions. Such ambition, of course, requires considerable study of the elements of engineering. It must be admitted that even the simplest of text-books on engineering subjects are couched in such language, or so hampered by mathematical formulæ, plain as they may be to those whose rudimentary education permits them to grasp their meaning, as to defeat their very purpose.

It has therefore been the aim in this course of lectures to present abstruse engineering facts in a simple and, it is hoped, as interesting a manner as possible. Should it succeed in helping some of that type for whom it has been written, the writer will feel much encouraged. Certainly these men, the oilers, coal-passers, watertenders and firemen of the world's merchant marine are deserving of the efforts of all who can be of any assistance to them. The transformation from sail to steam on the great oceans of the world has been so rapid that poets and writers generally are still sounding the praises in song and story of the old-time mariner and have not awakened to the fact that the sailor has been replaced by the man in the fireroom or engine-room. Some of the romance of the sea has disappeared with the sailorman, but heroism is as much, and more, in evidence with his begrimed successor. Where in the annals of seafarers was ever shown greater heroism than that displayed by the engineer's force of the ill-fated *Titanic,* who, almost to the man, sank with their ship and at their posts of duty? All the world knows that these hundreds of brawny artisans of the deep could have seized the boats and escaped with their lives; but they were men, and it is for the thousands of men like them that this book is written.

C. A. McAllister.

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McAndrew's Floating School

CHAPTER I

Introducing James Donald McAndrew

"I'm tired of shoveling coal and being bossed around," remarked Tom O'Rourke, one of a party of four husky young fellows who, at the end of a voyage, were just banking the fires in the stokehold on board the coasting steamer *Tuscarora,* then lying at her pier on the East River. This remark brought about a general laugh from the other members of the party. "Well," replied Jim Pierce, after the laugh had subsided, "what are you going to do about it? That's just what I've been thinking pretty strongly about; here I've been three years on this packet, working like a dog, and I don't see any chance of my ever getting anything better to do; of course, after a while, I may get a chance to squirt oil on that old mill of ours, but what I want to do is to get a 'ticket' and boss the job myself."

"Well, why don't you," rejoined Henry Nelson, another member of the party. "The Chief told me the other day that he had worked himself up from the bunkers, and he's pretty good at figures, too. If we only had the head on us that he has, we needn't wait long before the steamboat inspectors would pass us out the right kind of a paper."

Gus Schmidt, the fourth member of the party, had, during all this conversation, stood by quietly, drawing great puffs of smoke out of his five-cent meerschaum, and taking in everything that was said. As became his German ancestry,

he was stolid of disposition and not given to saying much unless he had something to say. Finally, after he thought it was his turn to get into the conversation, he said: "You fellows make me tired with all your pipe-dreams; why don't you get down to business; now I'll tell you what let's do. I just heard the 'Super' on the dock say to-day that the bunch of kettles in this ship are to come out, that we are going around to Philadelphia to get some new ones, and the ship is to be given a general overhauling at the same time, so as to put her in good shape for the next season's work. The Chief is going to boss the repairs, and the four of us are going to be kept by to chip and paint the coal bunkers and do some other high-class stunts like that. The whole job will last about six months, and as we won't have anything particular to do at night, let's buy some books and get the 'old man' to play school teacher for us."

"Fine business, Dutchy," said O'Rourke; "you've got a head on you like a clock. We'll go to it." The idea also met the approval of the other two, and it was decided to brace the genial Chief with the proposition.

James Donald McAndrew was a young man, not of French descent, as you no doubt may have surmised by this time, who was born on the great East Side in New York some thirty-eight years ago. Educated in the public schools until he was fourteen, he had successfully served an apprenticeship in a big general repair shop on the waterfront, and at the same time had gone to night school at Cooper Union, where, being naturally bright, he had become thoroughly grounded in the rudiments of an engineering education. Being fond of the water, he had shipped on board a twenty-five hundred ton steamer as a fireman, and in a very short time had taken out his license as a Third Assistant. Being naturally a hustler and capable of making friends among his superior officers, he found himself at the age of thirty-eight the Chief Engi-

neer on the *Tuscarora,* the biggest ship of the line. It was therefore quite in keeping that the Superintendent should have selected him as inspector of the extensive repairs the ship was about to undergo. Unlike many young men of his age who lead a seafaring existence, he took life somewhat seriously and had gone through the trying years of his development without falling into any bad habits. His father had died when the young man had just started in as a Third Assistant, which left upon him the responsibility of looking after his widowed mother and two young sisters. Consequently he was not given to wasting his money and could be found generally attending strictly to his business instead of roaming around town at nights when the ship was in port. His kindly disposition, ready wit and general all-around ability had won for him the respect of the crew, so he was not at all surprised this particular evening upon opening his stateroom door in response to a knock to find four members of the fireroom gang, hats in their hands, standing on the outside. "Well, boys, what can I do for you?" was his cheerful salutation.

O'Rourke, the self-constituted spokesman of the party, blurted out: "You see, Chief, it's this way; us four youngsters have an idea that we would like to get ahead in the world, and there don't seem to be much of a show for us if we don't get something in our heads. Dutchy Schmidt here thinks that if we will get some books, you might help us out when we get around to Philadelphia this winter putting in the new boilers. We'll have every night in, and as we will all live on the ship, we thought as how you might teach us something for an hour or so every night. We'll make it all right with you for the time you give us. What we want is to be able to get out our 'tickets' from the steamboat inspectors, and we know that you can give us the right steer."

"So you want to make me a school teacher, eh?" laughingly

rejoined McAndrew. "That isn't a bad idea, though, and if you fellows mean business and will get right down to brass tacks I might consider it. I want to tell you one thing right now, and that is if I do undertake such a job I don't want any monkey business. You'll have to study hard or you'll find me worse than any old Yankee schoolmaster you ever dreamed of. Before I sign up on this proposition I want to know something about each of you. Of course I know you are all pretty good firemen and 'tend to business, but what I must find out from each of you is something about how much of an education you have. I know you are not graduates of a high school or you wouldn't be here flirting with a slice-bar and wrestling with clinkers for a living. O'Rourke, let's hear your spiel first."

"Well, sir," replied that worthy, "I ain't much on book learning, but I can write pretty well, understand arithmetic, have studied geography and know a little something about history. When I was a boy I used to know the Catechism from one end to the other, but I'm a little shy on that now."

"Never mind," said McAndrew, "this will be no Sunday school you are going to tackle. How about you, Nelson?"

That descendant of some Norse king gave an outline of his educational career which closely corresponded with O'Rourke's, excepting the Sunday school part. Schmidt and Pierce followed in about the same strain, so that the upshot of it all was that Mr. McAndrew considered his contemplated class was about on a par so far as their proposition was concerned.

"I can see right now that I am up against a hard proposition to train you fellows up so as to enable you to take out your papers, but as long as you mean business I am willing to try out your scheme," said the Chief.

"Thank you, sir," was the chorused reply from all four, as light-heartedly they took their departure. Had they been col-

lege boys one of them would probably have yelled out, "What's the matter with McAndrew?" to be self-answered in a raucous yell, "He's all right," etc., but they had not yet reached that high degree of culture.

CHAPTER II

School Opens

About two weeks later the *Tuscarora* steamed up the Delaware River to the shipyard where the repairs were to be made, fires were hauled, most of the crew discharged and preparations made to begin the work. The four young firemen and Mr. McAndrew were kept very busy for a time after the arrival of the ship, but it was finally decided that the school should begin on what happened to be the first Monday night of the month. The youngsters in the meantime had rigged up a pretty fair school room in the engineer's storeroom, and had hung up a good-sized blackboard on one of the bulkheads. No testimony was given as to just where they obtained this blackboard, but it is safe to say that the shipyard people must have contributed involuntarily from their pattern and paint shops toward the cause of education.

Monday night, shortly after supper, the first session of the McAndrew School commenced without any frills or formalities. There was no necessity for a roll-call, as a full attendance was in evidence. O'Rourke, Pierce, Nelson and Schmidt had each indulged in a clean shave for the momentous occasion, and McAndrew himself appeared a little more perked up than usual in honor of his debut as a teacher.

Assuming a demeanor somewhat in keeping with his new responsibilities, McAndrew addressed his class as follows: "Young men, we are about to start in our course of training.

I don't propose to turn out a lot of high-brows from this floating school, but what I do intend, if possible, is to drive enough theory, or whatever you call it, into you to enable you with practical experience to pass your examinations for a license as assistant engineer before any board you happen to go against. I have been making inquiries to find out just what branches you ought to be drilled on to pass the examination, and I find that the law actually requires only two subjects, and that is how to make calculations concerning a lever safety-valve and how to figure out the staying of the flat surfaces of a boiler. Of course, no man can be an engineer who understands only those problems, and you will find that before you ever get your 'ticket' you will have to get a good general idea of the whole subject, as these local boards are very thorough. These examinations won't be like the old stories they tell about the examinations held in the early days of the civil service, for example, of how a candidate for a job in the Custom House was asked, 'How many Hessians came over here during the Revolutionary War?' Not knowing definitely, he answered, 'A d——n sight more than went back,' and, as the story goes, he got the job. Another one was the candidate for the position of letter carrier, who, when asked, 'How many miles from the earth to the moon?' replied, 'If I have to deliver letters there I don't want the job.'"

"You will find that the questions which the steamboat inspectors ask you to answer will be only such as you must know to make successful marine engineers."

"I therefore propose to post you in a general way on the principal things a seagoing engineer ought to know. I take it for granted that all of you know enough about arithmetic to make ordinary calculations, so we will not waste any time in going over that subject, as you will get enough practice in it as we go along on the other subjects."

"At the start, I will insist on each of you getting a thorough

understanding of a few of the elementary definitions in what is known as mechanics, as no one connected in any way with engineering in any of its branches can make a success of it unless he does understand these underlying facts."

CHAPTER III

Force, Work and Power

"Come on, boys, let's turn to and get right at this business," said McAndrew to his class, as they assembled on the following night. "The first part of this course is going to be what you all need the most—a little instruction in elementary principles. There is no good of a man trying to put a roof on his house until he has at least a pretty fair foundation under it. As I have already told you, I don't want to go into any 'highbrow' theories with you, as both of us would be losing something valuable—I'd lose my time and you would lose your interest.

"In all branches of engineering the principal output is power in one form or another. Now, it is a safe bet that none of you knows exactly what power is. I want to get the right idea of it firmly impressed on your memory, so that you will not be like a certain Irishman I know of who, through political influence, got a job to run a small steam engine in the Capitol. A sightseer stopped to look at his engine one day, and asked the son of Erin what horsepower it was. 'Horsepower!' he ejaculated, 'horsepower be ——; don't you see that it runs be stame.'

"Now to understand what constitutes power you must consider three elements—force, distance and time. For instance, here is a block of iron which weighs 5 pounds. I lift it up 1 foot from the deck by using *force* to overcome its weight,

and in so doing I have performed *work,* which is measured in what is known as foot-pounds; that is, I have performed 5 foot-pounds of work by overcoming the weight of this 5-pound block through a *distance* of 1 foot. Now get that fixed in your mind, *force* is overcoming weight, and *work* is overcoming weight through distance or space. Now it wouldn't make any difference whether I lifted that 5-pound weight a foot high in a second or ten minutes so far as the term 'work' is concerned, but when you come to 'power' then there is another thing to be considered, and that is the *time* it takes to perform the work. In measuring anything you must have a standard upon which to base your measurements; thus you buy waste by the pound, oil by the gallon, etc., so the early engineers in looking for a standard on which to measure power quite naturally selected the horse, that faithful beast which carries or pulls all manner of burdens for mankind. As a result of experiments on a large number of horses in England many years ago, it was decided that at an average a horse could perform 33,000 foot-pounds of work in one minute; hence this was fixed as the now almost universally adopted standard 'horsepower' for all engines. Always keep in mind, therefore, that power consists of three things—force, distance and time. Later on I'll show you how to calculate the horsepower of an engine.

"The next foundation stone I want you to lay is to get the right idea of the so-called mechanical powers. Only the other day I heard Nelson say when he was working that small jack-screw, 'Gee! but this is a powerful little beggar.' Don't forget one thing right at the start; there never has been any kind of a machine invented where you can get more *power* out of it than you put in it. In fact, it is always a little less on account of the loss by friction. If that jack-screw appeared to lift a weight of several tons with comparative ease, you must remember that it only lifted it a few inches, while your

hand traveled a good many feet in working the bar. The fundamental principle of all the mechanical powers is that the weight, multiplied by the distance it moves through, is always equal to the force multiplied by the distance it moves through. Suppose we take this foot-rule and put it over a knife-edge on the 4-inch mark. On the short end we will put these two 1-inch nuts and on the long end we will put one such nut, and you see that they balance exactly. Why? Simply because $2 \times 4 = 1 \times 8 = 8$. That is the principle of the lever, and later on you will find that it is the principle of the lever safety valve about which you will have to know before you can ever get your 'ticket' from the steamboat inspector.

"The next thing you want to understand is the inclined plane. Suppose you want to put a barrel of oil on a truck. You can't lift it off the deck, so you go and get a plank, and, single-handed, you can roll it up and put it in the truck. How could you do it? Simply because you couldn't lift it bodily a distance of perhaps 3 feet you rolled it up a plank 10 feet long. In that manner, while the barrel was lifted vertically 3 feet, you were shoving it for a distance of 10 feet.

"A wedge is simply a double inclined plane; to open up a space ½ inch wide in a plank you often have to drive the wedge lengthwise eight or ten times that distance.

"The screw, such as that jack I was speaking of, is a combination of the lever and the inclined plane. When you take hold of the end of the bar and pull, it acts as a lever on the head of the jack-screw. The thread is simply an inclined plane wrapped around the bolt. Between the two you can exert a tremendous pressure to lift anything, but always remember the great number of times you have to pull that bar around, and compare the distance your hand travels with the short distance the weight is lifted, then the 'tremendous pressure' exerted won't seem to be so mysterious.

"There are several other so-called mechanical powers, but

they are all practically based on the principles of the lever and the inclined plane.

"No matter what tool or mechanical contrivance you are using, just try to reason out on the principles I have given you to-night how you are accomplishing the work. To-day, O'Rourke, when you were lifting that main-bearing cap, you know that you couldn't budge it alone, but you had no trouble in hoisting it up with the chain tackle. How do you account for that?"

O'Rourke scratched his head a bit and said, "Come to think of it I guess I did pull that chain about a mile before I got the cap up a foot; the next time I'll let the Dutchman 'hist' her up, while I take observations on how far he has to pull it."

"I see," said McAndrew, "that you'll make good as a scientist, as the first thing any of them learn is to let some other fellow do the manual labor."

CHAPTER IV

Heat, Combustion and the Generation of Steam

"Having told you something about mechanical powers, I now propose to continue still further my remarks on elementary principles, and will take up the subjects of heat, steam, combustion, etc. In starting off I will ask you what is steam?" As no one else seemed to volunteer an answer, O'Rourke blurted out, "It's a white gas that kills you if you breathe it."

"It will kill you all right, but please remember that steam is not white until it is condensed into small particles of water —when it is formed in a boiler it is as colorless and invisible as the air. I am afraid, however, that your idea of steam is somewhat cloudy. Of course, you all know that when you shovel coal in a furnace, and boil the water in the boiler, steam is formed; but how? is the question.

"Heat, scientific men inform us, is a mode of motion. All substances are composed of infinitesimal small particles called molecules. Heat is the violent motion of these molecules, and may be occasioned in two fundamental ways. The first is what may be termed chemical action or combustion, and that is what interests us most. The element known as carbon, of which coal is largely composed, unites with another element known as oxygen, and heat is generated. Thus we put coal containing carbon in a furnace and admit air containing oxygen

through the grate bars, and heat results from the chemical union of the two elements. They must unite in certain proportions, so that is the reason you have to regulate the dampers and ash-pit doors. The right proportion is one part of carbon and two parts of oxygen. Always remember that the air is just as essential in forming heat as is the coal."

"The air is much easier shoveling," broke in O'Rourke. Not paying any attention to the interruption, McAndrew continued: "The right kind of a fireman is the one who pays attention to his fires and allows the proper mixture of air to reach the fires. If you put in too much coal, such as the 'crown-sheeters,' which O'Rourke likes to carry, the air does not have sufficient chance to circulate through the hot coals to make good combustion. If the clinkers and ashes are allowed to collect on the grates, they also shut off the proper amount of air and your fires get dead. Hence the best way to make steam is to carry a fire of uniform thickness, not more than 6 to 8 inches deep, and by means of the slice-bars keep the ashes off the grates as much as possible. Another thing is to keep your doors shut as much as you can; too much air is as bad as too little. When you have to throw in coal do it quickly, and spread it evenly over the fires. If the conditions are such that there is one part of the oxygen to one of carbon, you will not make much steam, as such a mixture does not burn—simply smells bad.

"As I told you before, there is a method of measuring everything by comparing it with some standard. This applies to heat as much as it does to coal itself, only you do not measure heat by its weight, as it has none; therefore we must measure it by its effect. One of the effects of applying heat to metals is to cause them to expand or grow larger. Taking advantage of this quality the thermometer was invented, which records the expansion and contraction of mercury in a glass tube as heat is applied. While the thermometer measures the

degree of the heat in a relative manner it does not measure the amount. Hence a unit amount of heat was decided to be the amount necessary to raise 1 pound of water 1 degree on the thermometer. They call that amount a British thermal unit."

Schmidt was very much interested in this term and remarked, "I suppose O'Rourke would rather have it called an Irish unit."

"Now it may interest you to know that a pound of good coal ought to produce something more than 13,000 of these British thermal units. Remember that, for by the time you boys get to be chief engineers everybody will be buying coal by the number of British thermal units it contains instead of specifying some particular brand of coal, as is done now. If you are not buying coal you will be buying fuel oil; but even so you will want to know the thermal units it contains.

"In order not to give you any wrong impressions as to the amount of air necessary for combustion, I want to tell you that for every pound of average coal there are needed about two and two-thirds pounds of oxygen. As the air contains only about one-quarter of its weight in oxygen, it is usual in order to obtain a good draft to admit about 20 pounds of air to the pound of coal. That means that approximately 250 cubic feet of air must be admitted to the furnaces for every pound of coal that is burned. Fortunately, the air costs nothing, or the process of making steam would be very expensive. Although I have advised you to keep the furnace doors open just as briefly as possible, do not forget that some air must be admitted above the fire in order to attain proper combustion. In all well-designed furnace fronts you will find a number of holes for the admission of air, so you must see that they are kept open.

"Now as to the other method of generating heat. All of you have noticed that if you rub your hand briskly over a

smooth piece of wood, for example, there is a sensation of warmth. That is due to the energy you exert in the rubbing process. If you do not keep a crank-pin well oiled you know that it will soon become heated up, and if it is allowed to go far enough it is quite possible that sparks would fly or the metal become so heated as to show color. This is but another example of energy being transformed into heat. You all know that the heat from the steam is quite readily turned into power or energy in the engine, so there must be some standard system of comparing one with the other. I have already told you that work is measured in foot-pounds, and that heat is measured in British thermal units. A scientific man named Joule therefore determined that 772 foot-pounds of work was equivalent to a British thermal unit, and that is the way that comparisons are made. O'Rourke, you are quite a strong young man, but you can see that if you hustled as fast as possible, you would not be able to turn out as much work as even 1 pound of coal. That shows you the difference between using your muscles and your brains. Coal is a very cheap and able competitor of the man who only uses his physical strength, but fortunately for mankind brains cannot be bought so cheaply.

"We have seen how heat is generated from coal, and you must keep in mind that heat is the source of all power for marine propulsion. Water is found to be the ideal means of conveyance for transforming the heat into power; it is easily converted into steam and it exists in great abundance. Hence the large majority of marine engines are designed to work by steam generated from water. You know that the result of starting fires in a boiler containing water is the generation of steam. If you put a thermometer in the boiler water you would see that some time after the fires are started the temperature would gradually rise until it reached the boiling point, usually taken at 212 degrees above zero. The heat thus ap-

plied is known as sensible heat, from the fact that it is apparent to the senses. After having reached that temperature it takes considerable time until steam is finally formed. This is due to the fact that for water to be turned into steam a great amount of heat is necessary to break up the liquid water and transform it into the vapor—steam. The heat thus absorbed by the water in the transformation is known as the 'latent' heat. To bring about this change there are required 966 British thermal units per pound of water, while it only took 152 British thermal units per pound of water to raise it from the temperature it was put into the boiler, say at 60 degrees, to the boiling point."

"Does this latent heat burn you as much as the other kind of heat?" said Pierce.

"Try it and see," replied McAndrew. "If you stick your hand in water at the boiling temperature I don't believe you will care whether the heat is 'sensible' or 'latent.'"

"If he's sensible I think he will keep his hand out of it," broke in the irrepressible O'Rourke.

"Now," continued the instructor, "you have sometimes heard the expression 'saturated' steam, and I suppose you think that something must have been mixed with it; but that is not the meaning at all. It really means steam in its natural condition; that is, for every pound pressure on the boiler there is a certain temperature corresponding."

O'Rourke whispered to Schmidt, "I'm on; now I know why they say a man is 'saturated,' like that drunken oiler we had last trip; it was *his* natural condition all right."

"If more heat is added to the steam than is due to that of its pressure then we have what is known as 'superheated' steam; and people are waking up to the fact nowadays, after discarding the use of superheated steam years ago, that there is real economy in it. I think that before long you will see nearly all marine engines using superheated steam.

"If the steam was generated under an atmospheric pressure only, a cubic inch of water would form 1,663 cubic inches of steam. To memorize that fact keep in mind that a cubic inch of water will make nearly 1 cubic foot of steam. Don't follow that rule too strictly, or some time you may be as badly off as the old lady who, when asked for a pound of shot and not having any scales, remembered the old rule, 'A pint's a pound the world around,' and gave the purchaser a pint of shot. Right here let me warn you about using these old approximate rules too freely unless you really understand why they are used and know the correct ones. Engineering is an exact science, and it does not pay to guess at anything.

"Steam, however, is not generated in boilers under atmospheric pressure; therefore I want you to know that while water will begin to boil at a sensible heat of 212 degrees when the steam is unconfined, as the pressure rises, the boiling point is raised correspondingly. Thus at 20 pounds pressure it will not boil until the temperature is 228 degrees, at 50 pounds pressure at 281 degrees, at 160 pounds at 363.6 degrees, and so on. Perhaps I should tell you here that the pressures I have given are what are known as absolute pressures, and I surmise that you do not know what that term means. It probably has never occurred to you that air weighs something; you breathe it and move through it as if it did not cause any particular resistance, but the pressure is there just the same. Now to understand it you must consider that the atmosphere we move around in is similar to water; the deeper you go in it the greater is the pressure, but as we are generally at the bottom of the air, which is at the level of the sea, we usually have the greatest pressure attainable, and it amounts to 14.7 pounds per square inch. In some foreign countries they speak of the pressure on the boiler not as so many pounds per square inch but as so many 'atmospheres.' Thus a pressure of 10 atmospheres, you can quite readily understand, is ten

times 14.7 pounds, or 147 pounds gage pressure. If you were at the top of a high mountain, the air pressure would not be so great and water would boil at a less temperature than 212 degrees. The steam gages on a boiler always record the pressure above the atmosphere; hence to find the absolute pressure of steam you must add to the apparent pressure shown on the steam gage the constant 14.7. This is important for you to remember, for later on when we get to talking about pressures in triple-expansion engines and turbines you must forget about steam-gage pressures and deal in absolute pressures."

"How is it," asked Schmidt, "that this atmospheric pressure don't crush in our ribs?"

"That's a good question," replied the Chief, "and I'll answer you by asking you one. How is it that a thin box without a lid on, sunk at the bottom in 25 feet of water, is not crushed by the water pressure? I'll also tell you the answer, and that is because the water is on both sides of the walls of the box, and it is consequently balanced. So with the human system, we breathe air and get it inside of us and there is a balance. Now if that thin box had a lid on it and was watertight the sides would be crushed by the water pressure."

"Gee!" interrupted O'Rourke, "I'll keep my lid off after this! I don't want my sides crushed in!"

"No danger of that," retorted Schmidt. "You are not watertight—you've got a leak in your throat."

"Following this discussion on the pressure of air, we might as well take up the question of 'vacuum' and get a good idea of that. O'Rourke, what do you understand is meant by a 'vacuum'?"

"Why—er—let me see," replied the talkative one. "Why—er—it's something in the condenser that sucks in your hand if you put it over the air cock."

McAndrew smiled and said, "No; it is something that is

not in the condenser, and your hand is not 'sucked in' but forced in by the pressure outside; otherwise, O'Rourke, your answer is excellent. You made two guesses and got them both wrong. You might have gone further in your lucid description and said that it was something which smelled bad. The term vacuum really means the absence of air, or the absolute zero of pressure. I have just told you that the air under normal conditions, at the level of the sea, weighs 14.7 pounds per square inch. Now if you pump out all the air from a box or other receptacle there is no pressure in it because there is no air. If a small amount of air is allowed to rush in there will be, naturally, a small pressure, but how much? That is what we want to know, as there must be some means of measuring it. You all have learned undoubtedly that this ship carries 26 inches of vacuum when we are running. That comes from the fact that some early scientific fellow learned by experiment that the pressure of the atmosphere (14.7 pounds per square inch) was the same as the weight of a column of mercury, or quicksilver, as you may know it, 29.74 inches in height. In other words, a perfect vacuum, or the absence of all air in a condenser, would be shown on the vacuum gage as 29.74 inches. If a small amount of air be admitted the needle on the gage would show a vacuum of less than that, as the balance between the air and the mercury would be disturbed. Finally, if the condenser was opened so that air could rush in freely, the needle would go back to the zero mark. It is customary, therefore, to speak of carrying a vacuum of so many inches, but don't ever speak of having a vacuum of over 30 inches, or people will think you are foolish. As a matter of fact, it is quite difficult on ordinary ships to get a vacuum much over 28 or 28½ inches. As 2 inches of vacuum is equivalent to 1 pound of pressure you can see how valuable it is for the working of the engine to have as great a vacuum as possible.

"While on the subject of vacuum, it will be well for us to take up the subject of how far a pump will lift water. After all this is very simple, as the pump does not lift the water at all; it simply pumps out the air, and the air pressure from without forces the water up the suction pipe. On the same principle as the column of mercury, it has been determined that the unit weight of air (the atmospheric pressure) will sustain the weight of a column of water about 33.5 feet in height, and that is the maximum height that water can be lifted by a pump, so never try to pump water through a suction pipe any higher than that. You can *force* it to almost any height necessary, but you can't *lift* it any higher than 33.5 feet. There is an old saying that 'Nature abhors a vacuum." It is not so much an abhorrence as it is the universal tendency of Nature to maintain things in an equilibrium or balance. If you disturb this balance by removing the air from anything, the outside air, water or whatever medium it is, will rush in to restore the equilibrium."

Just then, Pierce, who had been leaning back in his chair, intensely interested in what was being said, fell over backwards, much to the amusement of O'Rourke, who remarked, "There she goes again; Nature is restoring his balance!"

CHAPTER V

Engineering Materials

McAndrew, feeling somewhat encouraged at the interest which his class had shown during his remarks on elementary principles, decided that the next step in order would be to give them an idea of engineering materials, so he opened his remarks by saying: "Boys, what material is a cold chisel made from?" Three of them answered promptly, "Steel, sir." O'Rourke dissented somewhat by saying that he thought the one he had been using that day must have been made of lead, as he had to grind it so often. Paying no attention to the sally, the engineer pedagogue said: "Well, what is the difference between steel and iron?" As a deep silence followed the question, he remarked: "I thought you didn't know, and that's the reason I asked you. Since you have, I hope, absorbed a few ideas about elementary principles in engineering, I want to drill into you some idea of the materials used in building marine machinery.

"The first and most important of them is iron, man's most valuable metal." "What about gold, sir?" interjected O'Rourke. "I'm glad you spoke about that, as it shows that you think what most other people do. As a matter of fact, we could get along very well without gold, but we would have hard sledding to get along without iron. Gold is only valuable because of its scarcity, while iron is valuable on account of its usefulness. Luckily, it is found in great quantities in

almost all parts of the world, and as it would be practically impossible to build marine machinery without it, we will try and see what cast iron really is.

"Since the days of old Tubal Cain, iron has been mined and utilized by mankind for all kinds of implements. It exists in a number of different combinations known as ores, some containing as high as 75 percent of pure iron. The first process after it is taken from the ground is to separate the iron from the other substances, and this is done in what are known as blast furnaces. The scheme is to mix the iron ore with coal or other fuel and melt the whole mass down by means of forced combustion of the coal, hence the term 'blast furnace.' The molten iron being heavier than the other substances, is drawn off at the bottom of the furnace, and being liquid is run along channels in a bed of sand, known as the pig bed, into depressions or molds in the sand about 3½ feet long, 6 inches wide and 4 or 5 inches deep. When these are cold they are known as 'pigs,' and thus we have the raw material known as pig iron.

"Pig iron, of course, varies in quality, as it is affected largely by the impurities of the coal, such as sulphur, silicon, etc., which get mixed with it during the melting process. In olden days, before wood became so scarce, and there were no Pinchots to say 'Woodman, spare that tree,' iron ore was melted down with charcoal, and consequently not so many impurities entered into the pig iron. That metal was then known as charcoal iron, and you can yet hear old timers bemoan the fact that they get so little of it these days. And it is a fact that genuine charcoal iron is now very scarce indeed. However, we get along quite well without it by having learned to make steel better and cheaper than the pioneers could.

"Now that you know something about cast iron, we will see for what purposes it is used on board ship. You all

probably know that the cylinders are made of cast iron, always have been and always will be, as it cannot be improved upon for the purpose. It has sufficient strength to withstand the strain, will not melt or change under the heat, is readily machined, can be made into almost any form, becomes very smooth on wearing surfaces, and, above all, is very reasonable in price. That combination of qualities can never be excelled by any known metal."

"How strong is cast iron?" said Pierce.

"That's a good question," was the reply. "As I told you before, everything to be measured must have some standard of comparison. In the case of cast iron, the usual standard is what is known as its tensile strength per square inch. That means the number of pounds it would take to pull a bar one inch square, or one square inch in section, until it breaks. It is placed in a testing machine, which works very much on the principle of a beam weighing machine, and the weight or strain is gradually applied until the test piece breaks in two. The strength of the metal varies according to its quality and treatment, and its quality usually depends on the amount of impurities contained in the metal.

"First-class iron, such as used in cylinders, frequently has a tensile strength between 25,000 and 30,000 pounds per square inch. Other and poorer grades, such as are used in grate bars, furnace fittings, etc., have a strength of only 10,000 to 15,000 pounds to the square inch.

"Rigidity is the main feature of cast iron, and other tests, such as crushing and bending, are given to it, yet for all practical purposes the marine engineer is satisfied to know that it has the required tensile strength, as that is generally a guarantee that it will withstand any crushing or bending strains that will be placed upon it.

"Bedplates and condenser shells or walls are made of cast iron of fairly good quality, but need not be of such good

material as that used for the cylinders. Guides, pistons, etc., are usually made of the best quality of iron.

"What is wrought iron, did you say? That's something you hear about, but very seldom see these days. Strictly speaking, wrought iron is literally pure iron, or iron with all other ingredients removed. Before we knew so much about steel making there were large quantities of wrought iron used about a ship; in fact, the ship's hull itself was built of it. The process of making it was to melt cast iron in what was known as a reverberatory furnace—that is, a furnace where the iron came in contact with the flame but not the fuel. By this means the carbon, etc., was burned out of the molten mass as well as could be, and men called puddlers stuck a bar into the boiling iron, rolled up a ball of it, like you would taffy, put it under a squeezer or hammer to squeeze out the dross, then either hammered or rolled it out into bars or sheets. This material could be forged, welded or rolled into almost any shape desired. The process of its manufacture was slow and expensive, and it has now been practically abandoned.

"Before I go any further I want to impress upon you the main distinction between cast iron, wrought iron and steel. Remember these fundamental facts and you will have the general idea:

"1. Wrought iron is pure iron with very little or no carbon in it.

"2. Steel is pure iron mixed with from one-tenth of one percent to sometimes one and two-tenths percent of carbon, according to the grade of steel required.

"3. Cast iron is iron mixed with about 3½ percent of carbon, and with certain combinations even a higher percentage than that.

"You will thus see that the main distinction between these different grades of material is the amount of carbon they contain. To be sure, there are other ingredients in the mixture,

such as sulphur, manganese and silicon in varying quantities. Sulphur is always bad, but certain small amounts of manganese and silicon are beneficial."

"What is this malleable iron we hear about?" inquired Pierce of the instructor.

"Malleable," replied McAndrew, "means capable of being hammered or rolled into shape, and although it sounds very good when applied to cast iron, you don't want to hammer it too vigorously or you will find that it will take the shape of two or three separate pieces, such as that two-inch elbow I saw O'Rourke wrestling with this afternoon."

"I didn't think you was looking when I busted that elbow," replied the guilty one.

"I saw it all right, and let that be a lesson to you that all malleable iron is not as 'malleable' as you might imagine.

"In making iron castings malleable, they are packed in some substance, such as mill scale or sand which will not melt, heated to red heat and allowed to stand for a number of days, during which time some of the carbon is withdrawn from the surface of the castings, which to a certain extent makes them tougher and more ductile. This process is used principally for small castings, such as pipe fittings. Some people claim that malleable iron can be welded; so, to demonstrate whether that claim is true or not, I'll have O'Rourke weld up that elbow he broke."

"Gee! I wish you would let me buy a new one instead," pleaded the Irish lad. "I'm not much on this scientific dope."

"To return to the subject," said McAndrew, "we will next take up the subject of steel, as used for shipbuilding.

"There are two principal processes used in the manufacture of structural steel, the Bessemer and open-hearth. As Bessemer steel is not used in any part of a ship, it will suffice to discuss the open-hearth process.

"This consists essentially of melting pig iron, scrap steel and

wrought iron in a large circular furnace, sometimes as large as 20 feet in diameter, the heat being furnished by the combustion of gas over the top of the metal, so that, unlike a blast furnace, the fuel does not come in contact with the metal. This results in burning out the carbon in the mixture to a degree slightly less than that required in the steel to be made. In order to get the exact proportion of carbon required in the mixture, a certain amount of 'spiegel-eisen' is added."

"What's that, sir?" inquired O'Rourke.

"Ask your German friend," replied McAndrew.

"I don't know just what 'spiegel-eisen' is," replied Schmidt, "but in German it means looking-glass iron."

"That's right," said the instructor. "It gets its name from its bright surface, and it is really an iron ore containing a large proportion of manganese. This manganese unites with the oxygen and sulphur in the mixture and removes them. Spiegel-eisen also adds the requisite amount of carbon to the mixture. After it is determined by the man in charge of the furnace that the desired mixture is reached, the molten steel is run into ladles, from which it is poured into large molds which shape the metal into huge blocks of steel known as ingots. These ingots are, when needed, heated in a fiery retort to almost a white heat, and run back and forth through rolls until they are shaped into what are known technically as slabs and billets. In that shape they are selected to fill orders for boiler or ship plates and engine forgings, such as shafting, piston and connecting rods, columns, valve stems, etc."

"How can you tell this open-hearth steel from wrought iron?" inquired Nelson.

"Easy enough," interjected O'Rourke, "ask the man you buy it from!"

"That would be all right," said McAndrew, "if he knew the difference himself. As a matter of fact, it is very difficult

to tell from appearances. Some people claim that they can tell by looking at it, but I have my doubts as to that. Others who are expert in working iron and steel can be reasonably sure by the way they cut. I remember once of being in doubt whether a certain lot of boiler tubes were of wrought iron or mild steel, and I could find no one who was absolutely sure as to the material of which they were made. There is one infallible way, however, of telling, and that is by cutting the metal in two, polishing up the surface and pouring on a little nitric acid. In wrought iron there is bound to be a certain amount of slag in the mixture which strings out in the rolling process and gives the metal the appearance of having a grain. When nitric acid is applied, the pure iron is eaten away and leaves the grain sticking above the surface. Steel being practically a homogeneous metal is eaten away uniformly by the acid.

"The next most important metal for marine machinery is brass, and I'll ask O'Rourke to tell you what it is."

Clearing his throat and assuming an air of importance at being called upon for an expert opinion, the son of Erin replied: "Brass is a metal that is mined—I don't know just where; it costs like blazes, smells bad, is 'pisonous' to the skin, gets dirty in five minutes, and is used around an engine room principally for the purpose of keeping the poor firemen busy shining it up when they ought to be resting themselves."

"That certainly is a very lucid description, and coming from such an expert on 'brass' it will have great weight. However, I cannot agree with all your conclusions, and especially as to its being mined.

"Brass, as it is commonly termed, is not an elementary metal, as it is composed of two and sometimes three elements, such combinations of two or more metals being known generally as alloys. An alloy composed of copper and zinc, or

of copper, zinc and a very small amount of tin, is known as brass. When a larger proportion of tin or other metal, such as aluminum or lead, is used, the alloy is known as a bronze. As a matter of fact, the terms 'gun metal,' 'composition,' and 'bronze' are used rather loosely, and it is hard to draw a line of demarcation between them.

"The principal reasons for using brass, composition, bronze, etc., in the construction of marine machinery are their decreased friction when rubbed on other metals, their freedom from oxidization or corrosion, as it is commonly called, and in some instances for ornamentation. The latter reason is growing less every day, as there is plenty of other work on board a modern vessel to keep the firemen busy without having needless brasswork to polish.

"There are about a million different compositions of copper, tin, zinc, lead, antimony, iron, aluminum, etc., which can be made, but the principal ones of interest to marine engineers are the following, mixed in the proportions given:

"Common yellow brass: Copper, 65.3; zinc, 32.7; lead, 2.

"Babbit metal: Copper, 3.7; tin, 88.9; antimony, 7.4.

"Brazing metal: Copper, 84; zinc, 16.

"Admiralty bronze: Copper, 87; tin, 8; zinc, 5.

"Manganese bronze: Copper, 88.64; tin, 8.7; zinc, 1.57; iron, .72; lead, .30.

"Muntz metal: Copper, 60; zinc, 40.

"Navy composition: Copper, 88; tin, 10; zinc, 2.

"White metal: Lead, 88; antimony, 12.

"Phosphor bronze: Copper, 90 to 92; phosphide of tin, 10 to 8.

"Tobin bronze: Copper, 59 to 61; tin, 1 to 2; zinc, 37 to 38; iron, .1 to .2; antimony, .3 to .35.

"You probably will never be called upon to mix any of these compositions yourselves, and it is well that you will not,

as it takes an expert to do it. However, it will do you no harm to know what goes into the various metals with which you will have to deal.

"There is another alloy which is rapidly coming in use for marine machinery, known as 'Monel metal.' Unlike other compositions, it is mixed by Nature itself, as it is in reality nickel ore just as it is mined. It is composed principally of nickel and copper in about the proportion of 65 to 35. It has been found to be very efficient for valve seats in steam valves where superheated steam is used, for pump rods and valve stems, and for propellers. The tensile strength is equal to that of steel, and it is non-corrosive in salt water and acids.

"I have now described to you in a general way the principal materials used in an engine room——"

"You have left the main ones out, Chief!" said O'Rourke.

"What are they?"

"Why, the gold and silver that are handed out once a month."

"You'll have to know a good deal more about steel and brass than you do now before you can connect very strongly with those metals," retorted McAndrew, as he dismissed the class for the evening.

CHAPTER VI

Boilers

"We have now covered the most important of the fundamental subjects which all engineers should know, so we will begin on the subjects relating to the parts you are most interested in, that is, those with which you have already had some practice. I will therefore ask you what, in the opinion of each, is the most important thing to take up."

"Propellers," promptly replied Pierce; "they drive the ships."

"No, sir," said Schmidt, "let's take up the engines, for they drive the propellers."

"I think we ought to begin with boilers, sir," remarked Nelson; "they furnish the steam which drives the engines."

"Ah!" said O'Rourke, "if that's the reason, let's take up 'the walking of the ghost' when he comes across with the money that makes 'em all go."

"Nelson," said McAndrew, "has the right idea—the boilers are the most important parts of marine steam machinery. If you don't get the steam first, no matter how good the engines and propellers may be, the ship will not move.

"I have already told you what happened when coal is put in the furnaces, and now we want to know something about the boilers that hold the steam after it is made. How many kinds of boilers are there, O'Rourke?"

"Two, sir," replied that youngster; "tight ones and leaky ones."

"Well, that's a good distinction, but hardly the kind that we want to talk about, although I'll admit that a tight boiler of any description is better than any kind that leaks. If you were to study books on the subject you would have to read descriptions of a dozen types of shell boilers, but as there is practically only one type used on steamers nowadays, any knowledge you might gain about discarded types would be as useful to you as last year's bird nests. The principal type of shell boiler all marine engineers in the merchant service have to deal with now is the Scotch type—single or double-ended. By the time you boys get to be chief engineers even that type will probably be put on the shelf, as the day of the use of watertube boilers is fast approaching. However, as the Scotch boiler is just at present the principal one to be considered, we will give that first attention. This boiler is named, probably, from the fact that it was first developed by Scotch shipbuilders, than whom," said McAndrew, evidently taking pride in his ancestry, "there are no better in the world.

"Up to the present time it has stood the test of service better than any others of the class of shell boilers, and has consequently lived to see the others discarded. Theoretically, an ideal shell boiler, to withstand internal pressure, would be one shaped like a sphere or ball, as curved surfaces need no bracing; flat surfaces should be avoided in boiler work, and the principal feature of a Scotch boiler, which makes it so efficient, is that there are as few flat surfaces as possible. The shell of the boiler is made cylindrical, the furnaces are cylindrical, as also, of course, are the tubes. Consequently, the only flat surfaces are the heads and portions of the combustion chambers.

"The thickness of the boiler shell depends upon three things: the steam pressure to be carried, the diameter of the boiler and the strength of the material used. The steam pressure has gradually been increased, so that now it is not

uncommon to find Scotch boilers carrying from 200 to 250 pounds pressure; the diameter has increased so that boilers 16 to 18 feet in diameter are not rare. The time is not far distant when the shells will have to be so thick as to make this type impracticable; then you will see the watertube boilers come into greater use.

"In the early days of steam machinery, boiler building was a crude art. Compared with modern methods of construction it was in about the same relation as early wooden shipbuilding bears to modern steel shipbuilding. If a ship carpenter made anything that came within a half inch of the dimensions of the stick of timber he was shaping, he was supposed to be quite accurate. Old-time boiler makers were just about as crude; they rarely had drawings to follow, a rough sketch on a blackboard in the boiler shop sufficing; holes were always punched, and the drift-pin was used almost continuously. While such methods were all right for boilers using low steam pressures, they would not do nowadays at all. With the high steam pressures now used, and the large size of the boilers, nothing but accurate design and good workmanship will do. In the early days of boiler construction all rivets were driven by hand; now nearly all rivets are driven by hydraulic pressure of 15 to 30 tons, and even with that it is almost impossible to keep some of the seams and rivets from leaking.

"Here is a drawing (Fig. 1) of a typical small Scotch boiler which will show the general features of this type. It consists essentially of four steel plates rolled up into the form of a cylinder which is known as the shell of the boiler. Each portion of the shell is known as a course. The courses are lapped over one another and riveted together by what are known as lap joints. The longitudinal seams come together and are joined by straps or narrow plates on the inside and outside, the whole when riveted together being

known as a butt-joint. In this shell are two, three, or sometimes four smaller cylindrical furnaces which are riveted to the combustion-chamber, a semi-cylindrical box with flat top, front and back, in which the combustion takes place.

"You will notice that these furnaces are not straight, but consist of a wavy contour. In this particular case they are known as suspension furnaces. Some of them have a series

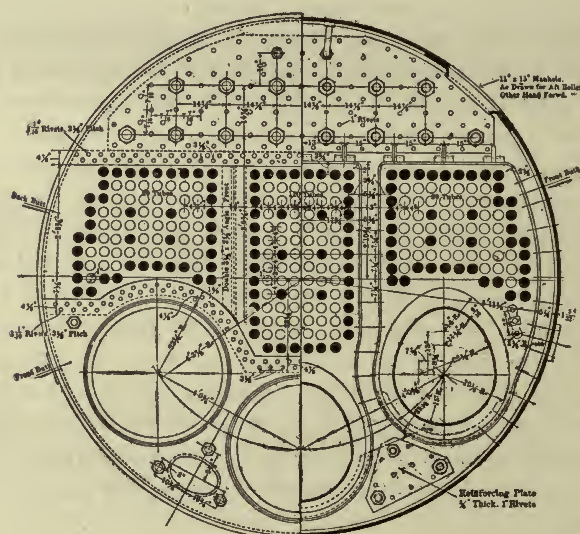

FIG. 1.—SCOTCH BOILER, END VIEW

of corrugations rolled into them, the object of both types being to give them sufficient strength to withstand the crushing strain brought upon them by the pressure of the steam. It is much easier for a cylindrical tank or figure to withstand an internal or bursting pressure than it is for it to withstand an external or collapsing pressure, hence all furnaces (in Scotch boilers) subjected to high pressures of steam on the

outside must be corrugated in order that they will not collapse under the pressure.

"From the combustion chamber to the front head are a number of small tubes, usually from 2 inches to 4 inches in diameter, through which the hot gases pass from the furnaces to the uptake and thence to the smoke stack. It is from these tubes where the greater portion of the steam is formed, as

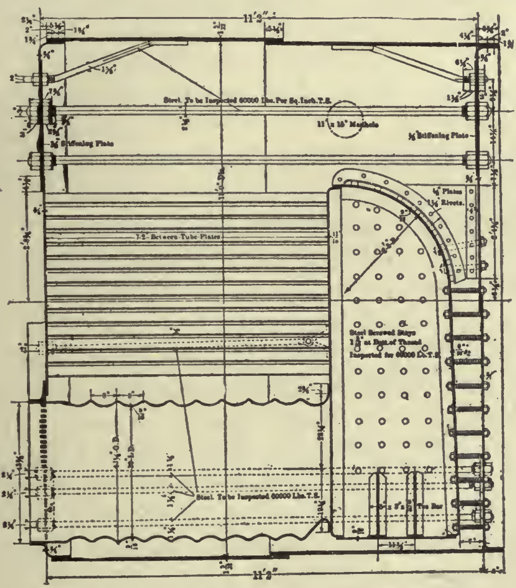

FIG. 2.—SCOTCH ROILER, LONGITUDINAL SECTION

they are usually from 1/16 to ⅛ inch in thickness, so that the heat from the gases is very readily transmitted to the water which surrounds them.

"As the heads of the boiler and the larger part of the combustion chambers are flat, they must be supported or braced at intervals in order that they may withstand the pressure brought upon them. Later on, I will teach you how to space

these braces or stays, as they are termed, as that is a question which will be asked before you can get your licenses.

"In the furnaces of a Scotch boiler the grate bars are arranged at about the middle at the front end and slope slightly downwards toward the back end. The length of the grates is generally about 6 feet, as that is about as far as a good husky fireman can work his fires properly. Sometimes they are 5½ feet or 6½ feet long, but in general you will find them averaging 6 feet in length. The capacity of the fireman in this respect really regulates the length of most Scotch boilers. Hence you will find that single-ended boilers very seldom exceed 11 or 12 feet in length, while double-ended boilers are generally about 20 to 22 feet in length—a double-ended Scotch boiler being practically two single-ended Scotch boilers placed back to back and joined together. As I said before, there are a number of other types of shell boilers, but as most of them are obsolete. we will not waste any time on them."

"What's obsleet?" inquired O'Rourke.

"'Obsolete' means old-fashioned, not up-to-date," replied the instructor.

"I see," replied O'Rourke; "it's something like that hat Schmidt wears when he goes to see his girl in Fishtown."

"We will now look into the watertube boiler question a little. This type of boiler is having a hard time in overcoming the prejudice against it. At first they were used in swift steam launches and torpedo boats, on account of the great saving in weight as compared with shell boilers. Old-time engineers viewed them as a sort of a necessary evil in that respect and pitied the men who had to run them. The battle for supremacy in speed between the various nations finally led the more daring designers to use them in some swift cruisers and gunboats. As no great harm seemed to have come of this, the more progressive designers finally adopted

this type of boiler for battleships. Old-timers shook their heads at this move and predicted dire disaster for the ships thus equipped. However, the results have been so satisfactory that to-day every new battleship throughout the world is fitted with watertube boilers, and they are giving the greatest satisfaction on account of their many superior qualities.

"O'Rourke, you of course know something about watertube boilers; how many classes of them do you think there are?"

"I don't know much about them myself," replied the young man, "but I heard a fellow out in the shipyard say to-day that there were two kinds, the macaroni and the spaghetti, whatever they mean."

"Ha! Ha!" laughed McAndrew. "I suppose he meant 'macaroni' boilers were those with large straight tubes, and 'spaghetti' as those having small, bent tubes. That is rather a good definition for the two main divisions of this class of boilers, but so far as different designs are concerned there must be two or three hundred, as every designer has his own ideas about getting up a watertube boiler. But these various kinds of boilers remind me of what they say about the fish in the waters around the Hawaiian Islands—there are 298 varieties, but they only use three of them to eat.

"In general, the main difference between Scotch and watertube boilers is that in the former the hot gases are inside the tubes and the water around the outside, while with the latter the water is inside the tubes and the gases around the outside.

"Watertube boilers usually consist of drums, headers and tubes, all inclosed in sheet metal casings. Usually there are one or two large drums on top and two or more smaller drums at the bottom, the tubes connecting the drums at the top and bottom. The feed water usually enters the boiler in the top drum, and is carried down to the lower drums through tubes or pipes known as down-flow tubes. Sometimes it flows down

through the tubes themselves. In any event a rapid circulation is started up between the water in the lower and upper drums or headers. As the water passes up through the tubes, globules of steam are formed which, discharging into the upper drum with the water, are separated by baffle plates from the water and pass out through the dry pipe into the main steam pipe. The tubes in which the steam is formed are known as generating tubes to distinguish them from downflow tubes when such are fitted to the boiler. Watertube boilers are usually rectangular or box-shaped, as the casing surrounds the tubes and the furnaces. In order to prevent the sheet metal casing from burning, it is usually lined with asbestos board and fire brick. Large tube boilers are those which have generating tubes 3, 4 or sometimes 5 inches in diameter. Boilers built of tubes 1 to 2 inches in diameter are classed as small tube or 'spaghetti' boilers, as O'Rourke's friend would say.

"Some engineers prefer one type and some the other, but if I had anything to say about fitting watertube boilers to a merchant vessel, the tubes would be as large as practicable and straight or nearly straight, so that they can be cleaned and examined."

"Why don't shipowners use watertube boilers in merchant vessels?" inquired Nelson.

"That's hard to answer," replied the Chief, "but I suppose it is for the same reason that many people refused to ride on the elevated road when it was first constructed in New York. They had been brought up to ride in corse cars on the streets: they knew they were safe and sure, and although they could ride faster on the elevated, they preferred the safety which they knew of, rather than to take a chance on the more modern means of transportation of which they were afraid. Such a trait of mankind is known as conservatism, and it is an

excellent quality until it is carried to excess, when it becomes foolishness.

"The advantages watertube boilers have over Scotch boilers are many. The weight of a watertube boiler, with water, is just about one-half that of a Scotch boiler under the same conditions, thus giving that much more cargo-carrying capacity. Steam can be raised in a half hour, as compared to four to six hours for raising steam in a Scotch boiler. There is less danger from a serious explosion, as the parts of a watertube boiler liable to explode are much smaller than the great bulk of a Scotch boiler, under pressure.

"A watertube boiler need never wear out entirely, as the various parts can be renewed as necessity requires. When a Scotch boiler wears out, it must be renewed in its entirety, and generally at great expense on account of tearing away the decks and joiner work above the boiler space.

"Watertube boilers can be forced much harder, with safety, than Scotch boilers, as they are in a manner flexible and can stand severe usage which ordinarily starts a Scotch boiler leaking.

"One of the main features which would appeal most, just now, to you boys, is the matter of cleaning. In watertube boilers there are no back connections to sweep—a task which makes the life of an old-time chimney-sweep seem easy in comparison—no crown sheets to clean and sometimes scale, no cleaning of the inside of the boiler, where a man must go through contortions like a ferret to get at the heating surfaces. I doubt if any more disagreeable job could have been devised in the days of the Inquisition than that which befalls the lot of a marine fireman when it is boiler cleaning time on board a ship fitted with Scotch boilers. Surely there is nothing which more discourages men from going to sea. No wonder engineers hurry and get fat as soon as possible, so that it is a physical impossibility for them to get through a 12 by

15 inch manhole. If the stokers and coal passers could vote on the type of boiler to be used, I am afraid the Scotch boiler would soon get in the class with Schmidt's hat.

"The disadvantages claimed by opponents of watertube boilers are that it takes more skill to tend the feed on account of the smaller quantity of water in the watertube type. This, I am told, is more imaginary than real, although it must be admitted that a water tender must be onto his job at all times and keep his eyes on the glass. So, too, should a water tender with any other type of boiler, as that is a duty where day dreaming does not go. It is also claimed that strictly fresh water must be fed into watertube boilers at all times, but, as a matter of fact, that is so with a modern Scotch boiler if its efficiency is to be maintained. The care of marine boilers of any type is one of the most important duties on board ship. Carelessness on the part of anyone connected with the handling of boilers is not only dangerous to all on board, but frequently results in large repair bills and operating expenses. The most successful engineers are those who keep the boilers in good condition and operate them intelligently."

CHAPTER VII

Boiler Fittings

"How many fittings are there on a marine boiler?" inquired McAndrew.

"Four, sir," said Nelson.

"Only four, eh? Well, what are they?"

"The steam gage, gage glass, shovel and slice bar," replied Nelson.

"Oh! come off," said O'Rourke, "the shovel and slice bar are what the highbrows call the 'implements of your trade'—they're not fittings."

"Well, O'Rourke," said the teacher, "how many do you think there are?"

"Oh! at least half a dozen," replied he, "but for the life of me I can't think of their names just now."

"O'Rourke, you remind me of the fellow who, when falling off the water wagon, paused in the act of taking a drink and said, 'There are a dozen good reasons why I shouldn't drink this whiskey, but for the life of me I can't think of one of them now'—and then he took the drink. I don't think you have tried very hard to think of the necessary fittings on a boiler, but, at any rate, I'll remind you of some of them.

"You all know of the safety valves, which are generally made in pairs and are bolted to the highest part of the boiler. The old-fashioned safety valves were of the ball-and-lever type, but they are not used to any great extent these days, as they are poorly adapted for high pressures, or in fact for use on shipboard at all. One of the most important duties about

the fireroom is to see that the so-called easing gear for lifting the safety valves off their seats is kept well oiled and in good working condition. At least every other day the valve should be lifted off its seat for an instant to see if the springs are working well. It might be necessary to open the safety valves in a hurry some day, and if the gear is not kept in good condition they would fail at the critical moment.

"The stop valves on boilers are very important fittings, as they control the passage of the steam to the engines. On every boiler you will find a large valve known as the main stop valve, and a smaller one, the auxiliary stop valve. These valves, too, should have their stems lubricated and kept in such condition that they can be worked easily. In this connection I want to warn you young men against opening a stop valve on a boiler suddenly—many a good man has gone to Kingdom Come by not bearing that in mind. You must remember that a sudden release of steam often causes large gulps of water to be carried with the steam through the valve and into the steam pipe, where a water hammer is instantly formed and often with the result of bursting the pipe. Even if no water is carried out with the steam, the pipes are cold, and the sudden condensation results also in a water hammer. When you open a stop valve, just 'crack' it at the start—by that I mean to turn the handwheel a mere trifle until you can hear the steam hissing through the slight opening. Then wait until you can count at least 200 before you give it another slight turn."

"It's too hot up there to be counting very much," interjected O'Rourke.

"Yes, but it isn't nearly so hot up there as the place you might go to if you opened the valve suddenly," said McAndrew.

"We have seen how to get the steam out of a boiler, but after all it is of even greater importance to get the water into

it, for if you fail to keep the water flowing into a boiler under steam, there would soon be something doing.

"Schmidt, do you know what a check valve is?"

"No, sir," replied he, "I don't know just what it is, but I know where it is, and I know that you open it to let the water in the boiler after you start the feed pump."

"That's something to know," continued McAndrew, "but like a certain brand of breakfast food, 'there's a reason for it.' A check valve is one which allows water to pass in only one direction—that is, from the pump to the boiler. It is made that way so that in case the feed pipe should burst, the scalding hot water and steam from the boiler would not rush out through the opening in the feed pipe."

"I'm on," said O'Rourke, "it's like a one-way ticket to Coney Island—you can get down there all right, but you can't get back if you blow in all your money."

"Recently all marine boilers were required to have two separate openings in the shell and two separate check valves, a main and an auxiliary, to regulate the admission of the feed water, so that if one gives out the other can be used. There is also a stop valve located between the check valve and the boiler shell, so that in case of accident to the check valve the stop valve can be closed and repairs made to the check. It pays to take every possible precaution in regard to such an important matter.

"After we have provided means for getting the water in and the steam out of a boiler, the next thing in importance is to have some way to ascertain the level or height of the water in the boiler. Here, too, every precaution must be taken, for it is a very serious matter. You all have seen the gage glasses and how careful the water tenders are to watch the level of the water in them. The gage glass is, therefore, the most important of the means employed for determining the water level. As a further precaution, there are four gage

cocks usually fitted on the side or in the front of the boilers at about the desired water level. I must confess that it is very difficult for anyone, except a locomotive engineer, to tell exactly the water level by means of these cocks. It takes a trained eye and a trained ear to distinguish between the steam and water when a ship is rolling. The locomotive engineer has to depend on gage cocks almost entirely, as it is impracticable to fit gage glasses on a locomotive. On board ship the men rely almost entirely on the gage glass, so they do not get much practice with the try cocks. I would rather take my chances by having two gage glasses fitted, as it is almost certain that both glasses will never be broken or out of order at the same time.

"I suppose you have noticed that toy safety valve just over the uptakes on our boilers. If you didn't see the main safety valves, you might get the idea that the boiler designer had put a boy to do a man's work. The object of this little valve, which should always be a lever valve with a sliding weight, is to give warning that the steam is almost up to the blowing-off point; hence it is known as a sentinel valve. If for any reason the springs in the safety valve refuse to work, this little valve is sometimes very useful.

"You, of course, have heard of the blow valves on the boilers. These are usually fitted to all boilers; one is known as the 'surface blow' and the other as the 'bottom blow.' In boiling water the lighter impurities, such as grease and other substances, which float on water, are driven to the surface of the water. O'Rourke, I know, has often watched his mother skim the grease off the top of the boiling pot of soup, when he was a boy and was so hungry he could hardly wait for dinner time. The idea of the surface blow on a steam boiler is about the same, only in a boiler there is a pipe connecting the blow valve to what is known as a 'scum pan,' usually located in about the center of the boiler and at about the low-

water level. At intervals it is advisable to open the surface blow valve and give it a slight blow in order to remove the grease and other floating impurities from the boiler water.

"The bottom blow valve is located at the lowest part of the boiler, and there is usually a perforated iron pipe connected to the blow valve. Mud and heavy impurities collect at the

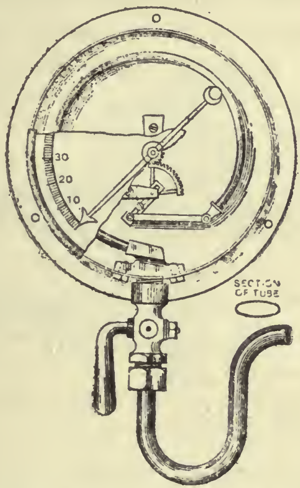

FIG. 3.—BOURDON STEAM GAGE

bottom of the boiler, and an occasional blow will remove such substances. This bottom blow is sometimes used to pump out the boiler when it is desired that it be emptied.

"One of the most important of the so-called 'boiler fittings' is the steam gage, for it is by means of this instrument that we are enabled to determine the actual pressure of the steam in the boiler.

"Fig. 3 is a picture of the type of steam gage usually fitted to marine boilers. By means of a circular tube having an elliptical section as shown, when the pressure is applied to the

inside of the tube it tends to assume a round section, and the tube itself tends to straighten out owing to the greater area subjected to pressure on the outside surface. The free end of the tube is connected by gear wheels and pinions to the needle on the face of the dial which, when properly adjusted, records the steam pressure. Remember, as I have called to your attention before, boiler gages only record the pressure above the atmosphere and not the absolute pressure.

"Steam gages on boilers should be tested at intervals to see that they are adjusted correctly, as it frequently happens that gages on different boilers, all connected up, show a variance of from 1 to 10 pounds. I once had a green fireman with me who nearly broke his back trying to get the steam on his boiler up to the same pressure carried by the other boiler; as a matter of fact, the gage on his boiler recorded 5 pounds less pressure, due to its being out of adjustment. The older firemen let him hustle for a day or so before they told him the gage was wrong."

"Why do they always put that crook in the pipe to the steam gage?" inquired Nelson.

"That's because most water tenders are so used to seeing snakes that they want things to look natural to them when they watch the steam gage," volunteered O'Rourke.

"O'Rourke is as nearly right as usual," replied McAndrew. "The real reason is that if the steam acted on the Bourdon tube direct, the expansion due to the varying temperatures would make it record inaccurately. Hence, the crook serves the purpose of a trap, as it fills with water by the condensation of the steam, and this water is forced into the tube by the steam.

"Another important fitting is the air cock, which is usually placed at the highest part of the boiler. When fires are started this cock should be opened in order that, as the steam is raised,

all the air in the boiler will be driven out. It should not be closed until live steam issues from the cock.

"To impress upon you the importance of paying attention to even the smallest details around boilers under steam, I want to call your attention to a boiler explosion on board an American vessel not many years ago, when over thirty lives were lost and great damage was done because a fireman who

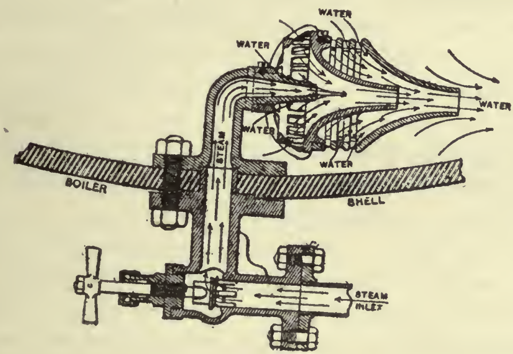

FIG. 4.—HYDROKINETER

was sent on top of the boilers to close the air cock not only closed that fitting but also shut off the cock in the small steam pipe which led to the steam gage. The result was that although no steam showed on the gage the pressure in the boiler rose to the bursting point and the explosion followed. Always remember that if you make a mistake like that you endanger not only your own life but the lives of everybody else on the ship.

"Some boilers are fitted with what is known as a 'hydrokineter,' which means literally a water heater.

"One of the great faults of all Scotch boilers is that the water under the furnaces and combustion chambers does not circulate properly, or, in other words, it is dead. The hydro-

kineter is usually located in this dead water, and when live steam is admitted it acts on the principle of an ejector and causes the water to circulate as indicated by the arrows in the sketch. I have seen boilers carrying over 100 pounds of steam when you could bear your hand on the bottom of the shell because of the presence of the dead water underneath the furnaces. Some engineers when raising steam will connect the auxiliary feed pump so as to draw this cold water out through the bottom-blow connection and discharge it through the auxiliary feed check valve, thus causing an artificial circulation. There are also several very good patented devices for bringing about this much desired circulation.

"Another item which might be classed as a boiler fitting is the so-called fusible plug which the law requires shall be fitted to the tops of combustion chambers and at other important parts of the boiler. This consists of a brass plug screwed into a tapped hole; the center of this plug is filled with a soft metal, such a Banca tin, which, when not covered by water, will melt and allow the steam to blow through the opening, thus acting as a safety vent."

CHAPTER VIII

Forced Draft

"Before leaving the subject of boilers, we will look into the matter of forced draft. Although this ship is not fitted with any system for that purpose, many other ships are, so it will be well for you to know about the various methods adopted.

"I have told you that air is just as important for combustion as coal itself. When fires are started in the furnaces the smoke and hot gases go up through the tubes and uptakes to the funnel or stack. You might wonder why they don't come back through the furnace and ash pit doors. The reason why they do not is due to what is known as draft, or the tendency to go up instead of down. Air when heated becomes less dense or lighter in weight, hence it is that at the furnace front and under the grate bars there is a tendency of the air to flow through and up. This tendency is due to the difference in weight of a column of cold air of the height equal to the distance between the level of the grates and the top of the stack, and the weight of a similar column of heated air of the same height. This difference in pressure or weight is usually very slight, but sufficient to cause enough air to flow into the furnaces to keep up a reasonable rate of combustion. In general, the higher the funnel the greater the difference in pressure, and consequently the better the draft.

"Draft is usually measured by a device such as is shown in Fig. 5. One end of the U-shaped tube, which is located in the fire-room, is open to the air pressure in the fire-room, the other is connected by a rubber tube to the space under the grates. The difference between the two pressures compels the

water to lower in the free end and rise in the end connected to the tube. We thus speak of draft as measured, not in pounds, but in inches or fractions of an inch of water. Were the pressure to be expressed in actual weight, such as a steam gage shows, you would find that 1 inch of water pressure would equal only two-thirds of an ounce.

"Ordinarily natural draft on a steamer of this size is about ¼ to ⅝ inch of water, and such a pressure under ordinary

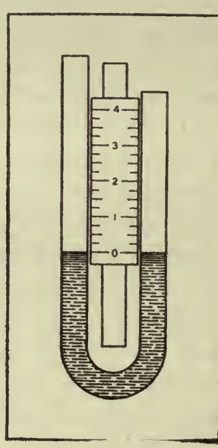

FIG. 5.—DRAFT GAGE

conditions is sufficient to burn enough coal to produce the desired speed of a vessel. There are times, however, when greater speed is demanded than can be produced by natural draft pressures. Fast passenger vessels, steam yachts and torpedo boats must go at full speed either all of the time or at intervals, and under these conditions a greater rate of combustion must be obtained. Hence it becomes necessary to use what is termed 'forced' draft, or in other words apparatus for furnishing a greater quantity of air to the furnace than

would naturally flow in due to the difference in weight of the two columns of air.

"The most primitive system of forced draft is probably illustrated by the boy who, while shooting firecrackers, blows on a piece of punk in order to make the cracker fuses light easier."

"Chief," interrupted Schmidt, "I think we could have a good forced draft system on board this ship by making O'Rourke get on his hands and knees and blow under the grate bars; he's about as good a blower as I know of."

"That's all right," retorted O'Rourke, "about my forced draft; I know some one not very far off who couldn't be used for that purpose—he eats too much Limburger—his breath would put out almost any fire instead of making it burn faster."

"If you young men are running a debating club, we had better quit right here and let you fight it out," said McAndrew.

"Please go on with the forced draft, Chief," pleaded Pierce, who was by far the most earnest of the Floating School undergraduates.

"To return to the subject," continued the instructor, "forced draft on board steam vessels is produced by one of four general systems.

"The first and most generally used is the closed fire-room type, where all parts of the fire-room and boiler compartment are made as nearly air-tight as practicable, and the air is forced into the space by means of centrifugal blowers, which draw in the air from ventilators or sometimes from the engine room and discharge directly into the fire-room. As there is no other escape except through the grate bar spaces, the fires are forced by means of the greatly increased amount of oxygen available for the purposes of combustion. This system is more comfortable for the firemen, as the cooler air from outside makes the temperature lower. It gives, however, a some-

what uncomfortable feeling in your ears, as the pressure is, of course, greater than the ordinary pressure of the atmosphere."

"Why can't you put cotton in your ears?" inquired Nelson.

"You could if you wanted to, but the pressure would be on the cotton just the same, and there would still be a feeling of pressure on your ear drums.

"A steam jet in the funnel is another system of forced draft, and probably the simplest that can be devised. The most efficient jet seems to be one that is located right in the center of the stack, and so proportioned as to blow the steam out through a conical opening, causing it to spread out to the sides of the stack and creating a lowering of the pressure in the up-take, which causes a more rapid flow of the air through the fires. Steam jets are not very economical for marine purposes, as they waste too much valuable fresh water.

"On harbor boats or on vessels running in fresh water, they provide a simple and inexpensive forced draft. All steam locomotives use what practically amounts to steam jet forced draft, as you probably know that the exhaust steam from the two cylinders is turned into the stack, which with the engine at full speed produces a very strong draft.

"Ash pit draft is another of the four systems used. In this the air is led from blowers through sheet iron ducts, directly to the ash pits, where it is discharged underneath the grate bars. When it becomes necessary to charge the furnace with coal the draft must be shut off, else the flames and gases will be forced out of the furnace doors into the faces of the firemen. The best type of ash pit forced draft is where the air from the blowers is passed through a heater arranged in the up-takes, whereby some of the heat which would otherwise be lost in the escaping gases is utilized in warming the air which is used for combustion.

"Induced draft is used on many vessels; this is caused by locating a large blower at the base of the stack, which draws

the gases from the up-takes and discharges them higher up in the stack or funnel. This is much less expensive than the closed fire-room system, and in case of any leaks in the breeching or up-takes the air from the outside rushes in, and thus prevents the escape of gases into the fire-room space, as frequently occurs when natural or forced draft of the other types is used.

"This will close my remarks on the subject of boilers, and as O'Rourke has fallen asleep twice in the last ten minutes, I think you had all better 'turn in.'"

CHAPTER IX

Engines

On the following evening McAndrew began his lecture by saying:

"Young men, we are now about to take up a subject which I know will interest you greatly, as you all hope to be engineers; that is, men capable of running and caring for engines.

"O'Rourke, what, in your opinion, is an engine?"

"Let me see," replied the spokesman of the class. "An engine is something that makes the wheels go around."

"You're right," replied McAndrew; "shorn of all qualifying verbiage that is really what it does, and that is its principal function. But how does it do it? that's the question. You all know that when everything is in readiness the man on watch opens the throttle and the screw begins to revolve. If that was the extent of your knowledge you would be simply engine starters and stoppers, but I trust you will know more about it before you get your licenses.

"As I told you before, if a cubic inch of water is turned into steam the latter would, under atmospheric pressure, expand into almost a cubic foot of steam. When, however, it is confined in a steam-tight vessel such as a boiler, it cannot expand into such a large volume, and consequently the pressure rises. When it reaches, say, a pressure of 180 pounds per square inch, it has a tendency to expand into the volume which it would occupy if all pressure were removed. It is this tendency to expand which makes steam valuable as a source of power, and the greater the pressure the greater the expansion. In

this connection you should remember the fundamental rule that the pressure multiplied by the volume is always equal. Thus if we have one cubic foot of steam at a pressure of 100 pounds per square inch, it has the same expansive effect as would 10 cubic feet of steam at a pressure of 10 pounds per square inch.

"When steam is released from the boiler and enters an engine, it tends to expand like a compressed spring if the weight is taken from it. When it reaches the cylinder of an engine through the pipe connecting the boiler to the cylinder it starts to expand, and as the sides of the cylinder and the cylinder head are fixed and rigid, the only way it can increase in volume is to force the movable piston in the cylinder up or down as the case may be. This up and down motion of the piston is transmitted through the piston and connecting rods of the engine to the crankshaft which rotates and turns the propeller.

"There have been numerous kinds of engines invented to utilize the expansive force of steam, and step by step they have been improved upon, until now practically nine-tenths of all the marine engines in use are of the vertical, inverted, triple and quadruple expansion types and the more recent type known as the turbine. Obsolete types, or those which have outlived their usefulness, are of interest to show what steps have had to be taken to reach the present standards, but for your purposes the modern engines are those to which you should devote most of your attention.

"Nelson, what is your definition of a triple-expansion engine?"

"One that has three cylinders, sir," he promptly replied.

"That is true in part," said McAndrew, "as the majority of triple-expansion engines do have three cylinders; but I want to disabuse your mind of the idea, which so many youngsters seem to have, that the number of cylinders determines the type of the engine. Some compound engines have three

cylinders, some triple-expansion engines have four and even five cylinders, so you see that your definition does not hold in all cases.

"Engines derive their classification or type from what we may call the different stages in which the expansive effect of the steam is utilized. A simple engine is one in which all of the expansive effect is utilized in one stage; a compound engine is one in which this is accomplished in two stages or periods; a triple expansion type is one in which it takes three stages of expansion to get all the work from the steam. Thus if we are using steam at 180 pounds gage pressure in the high-pressure cylinder (or first expansive stage) it partly expands during the first step to a pressure of, say, 60 pounds, when it is exhausted into the second stage, or the intermediate cylinder, as it is termed; there the expansive force is reduced to, say, 10 pounds gage pressure, when it again passes to another stage, or the low-pressure cylinder, in which it is expanded down to an absolute pressure of perhaps 2 pounds, depending upon the vacuum carried in the condenser. The whole process might be compared to wringing the water out of a tablecloth.

"Now, O'Rourke, I suppose when you were a boy you have helped your mother with the family wash on Mondays, haven't you?"

"Sure thing," he replied, "whenever I couldn't stick my kid brother on the job."

"Well, you might remember that your mother would take a tablecloth out of the bluing water and give it a twist, thus rinsing out considerable water; after a while she picked it up, took hold of one end of it while you took the other end, and you both twisted it as hard as you could, with the result that more water came out of it. Finally, she put it in the wringer, for which you probably furnished the motive power, and still more water ran out of it. Well, that's the idea of a triple-expansion engine; it takes three processes to get the

work out of the steam, just as it took three processes for you to get the water out of that tablecloth."

"Gee!" said O'Rourke, "I must have been a triple-expansion laundryman and didn't know it!"

"I think from the sound of the hot air which escapes from him he must have been a simple one," volunteered his rival, Schmidt.

"Having, I hope, fixed in your mind the idea of a triple-expansion engine, we will now investigate some of its parts. The cylinders, naturally, are the most important of these, as in them the work of the steam is performed.

"I suppose you know that the name comes from the geometrical figure known as a cylinder, as the inside or working surface of the so-called cylinders is perfectly cylindrical; that is, it is exactly circular in section at any point. The outside of a marine engine cylinder is anything but cylindrical, owing to the valve chests, flanges, etc., necessary to fit it for its work.

"All steam engine cylinders are made of cast iron, because that is the ideal material for the purpose; no other material would fulfill all the requirements.

"The thickness of cylinders depends upon several things, the most important of which is the strain which it is required to withstand. However, you will find that they are always made much heavier than actually necessary, as all parts of machinery are, when designed, given what is termed a 'factor of safety.' That is, after you have calculated how thick any part should be from a theoretical standpoint, you make it actually three, four or even five times as thick, then you will be deadsure that you are on the safe side. You might think from that statement that designing engineers do not have much nerve, and as a matter of fact many of them are lacking in that essential. Experience has, however, taught them to be on the safe side, for in marine machinery particularly emergencies develop in the most unusual way at times which upset all

theories. After cylinders have been in use for a number of years they may become badly scored or out of round, in either of which cases it is necessary to have them rebored. Consequently the designer must keep that contingency in mind when determining the thickness. You can always cut off portions of a casting, but you can rarely add anything to them, hence they should be heavy enough at the start.

"Attached to and cast with the cylinders are the valve chests which contain the valves for regulating the entrance and exit of the steam to and from the cylinders. They vary in size and shape in accordance with the type and sizes of valves used.

"The cylinder heads are, of course, a necessary adjunct to close up the tops of the cylinders. Relief valves are always fitted at the top and bottom of each cylinder to relieve any steam pressure in excess of the safe working pressure, but principally to relieve the cylinders of water pressure, in case, as may happen, water collects in the cylinders, either from being carried over from the boilers with the steam or from being condensed in the cylinders before they are properly warmed up. Water is, as you may have observed, practically non-compressible, so that if any collects either at the top or bottom of the cylinder, and the piston moves rapidly against it, something must give way. The relief valves, if properly adjusted, serve the purpose of allowing the water to escape and of preventing an accident to the head or to the cylinder itself.

"To prevent too great a radiation of heat from the cylinders they are lagged with blocks of a non-conductor, such as magnesia or asbestos, 1½ to 2 inches thick, held in place either by wood staving or planished sheet iron. This accomplishes two purposes: one of making the engine more efficient by preventing the loss of heat, and the other of keeping the engine room from becoming too hot for comfort.

"O'Rourke, do you know what a non-conductor is?"

"It must be a conductor that don't belong to the union," replied the Irishman.

"Oh! I'm not talking about street cars," testily replied McAndrew. "There are certain substances which transmit heat very readily, and they are termed 'conductors'; others which transmit heat very slowly are known as 'non-conductors.' It is often said that man cannot improve upon nature, and this is verified by the fact that hair-felt, made principally of cow hair or horse hair, is about the best non-conductor we can use. Hair-felt will burn or scorch if placed on surfaces which are too hot, such as the cylinders of an engine using high-pressure steam, hence combinations of asbestos and magnesia make the best non-conductors for that purpose.

"The next parts of a marine engine to be considered are the pistons and piston rods. The pistons are made either of cast iron or cast steel; sometimes for lightness, as in the case of those used in torpedo boat engines, they are made of wrought steel. If they are made flat and of box section, that is, with double walls, the material used is cast iron. However, the majority of pistons are cast solid of conical section to provide the necessary strength, and in this shape are almost invariably of cast steel. In first-class work they should be machined all over, so as to reduce the clearance spaces as much as possible. It is necessary, no matter what the type of piston used, to provide some means of preventing the steam from leaking past the piston. This is accomplished by rings fitted in grooves in the rim of the piston, which either from their natural elasticity or from being forced outward by springs of various forms, keep tight against the wall of the cylinder and prevent the leakage of steam. These rings are always made of cast iron, as no other metal will suffice. Great care is usually taken to prevent the steel pistons from wearing against the sides of the cylinders, as steel on iron is a bad combination where the surfaces are not thoroughly lubricated.

"The piston rods, which transmit the motion of the pistons

to the crossheads, are simply cylindrical columns, securely fastened to the pistons at the top and the crossheads at the bottom, by means of fitting into tapered holes, which take up the thrust in one direction and nuts which prevent movement in the other direction. Piston rods are almost invariably made of wrought steel, and to save weight are sometimes made hollow. Now I think I heard one of you fellows say, sometime ago, that a hollow piston rod is stronger than a solid one, or was it a hollow shaft you were talking about? Anyhow, you want to forget that, as I find too many people get that foolishness in their minds. A hollow rod or a hollow shaft is stronger than a solid one of the same weight, that is of the same amount of metal used, but you can see that if only the same amount of metal is used the solid rod or shaft will be of a smaller diameter. So hereafter you can say, for example, that a 6-inch hollow rod with a 3-inch hole through it is not as strong as a 6-inch solid rod, but that it is stronger than a 5¼-inch solid rod which contains the same amount of metal. Even then it is only stronger when the rod is being pressed down or in compression, as it is called; when it is being pulled, or is in tension, it would be of the same strength, whether hollow or solid, as there would be the same sectional amount of metal to transmit the pull."

"Why don't they make piston rods square instead of round?" inquired the studious Nelson.

"I'm glad you spoke of that," replied the instructor. "So far as actually transmitting the work is concerned I suppose a square rod would do as well as a round rod, but the rod must pass through the bottom of the cylinder so as not to allow the steam to escape. It would be very difficult indeed to build a stuffing-box around a square rod and keep it tight, whereas with a round rod it is comparatively simple. Another reason is that it is much cheaper to machine a round rod than it is a square one. In passing it will be well to consider

the manner in which steam is prevented from leaking out of the cylinders around the piston rods and valve stems. In the olden days when the steam pressures and consequent temperatures were low, it was quite an easy matter to keep rods tight by a simple stuffing-box with an adjustable gland, packed with hemp or other form of soft packing. Nowadays the steam pressures and temperatures are so high that they would soon burn or blow out hemp packing, and the result is that metallic packing has to be used. This has been a fertile field for the inventor, with the result that almost every day a chief engineer, when in port, will be met by a man with a new kind of packing, guaranteed to be better than any other kind ever made and capable of saving at least 10 percent in the coal bills. Metallic packing usually consists of rings of cast iron, white metal or composition, held against the rod by the compression of springs of ingenious forms. The best of them is the one that keeps the rod the tightest with the least amount of friction."

"What kind is that?" said O'Rourke.

"You can search me," replied McAndrew. "Now, having described the principal features of cylinders, we must, in regular order, find what they stand on, or what it is that supports them, as you all know that the cylinders must be held in place as rigidly as possible.

"What name is given to these supports, O'Rourke?"

"'Colyums,' sir!" replied the one addressed.

"Oh! you are learning fast," said the instructor, "nearly all old-timers refer to them as 'col-yums' instead of 'col-umns,' as the word should properly be pronounced.

"Columns are made of numerous designs—of cast iron, cast steel and wrought steel. Some engines are supported on cast iron box-section columns at front and back, but I think the majority of marine engines have cast iron inverted Y-columns at the back and cylindrical wrought steel columns

at the front, as shown in Fig. 6, where sections are shown also. In nearly all merchant vessels' engines the condenser is built in the engine frame and forms a part of the support for the cylinders. Short columns, to which the guides are attached, are bolted to the top of the condenser."

"I thought guides were men who show 'rubes' around the

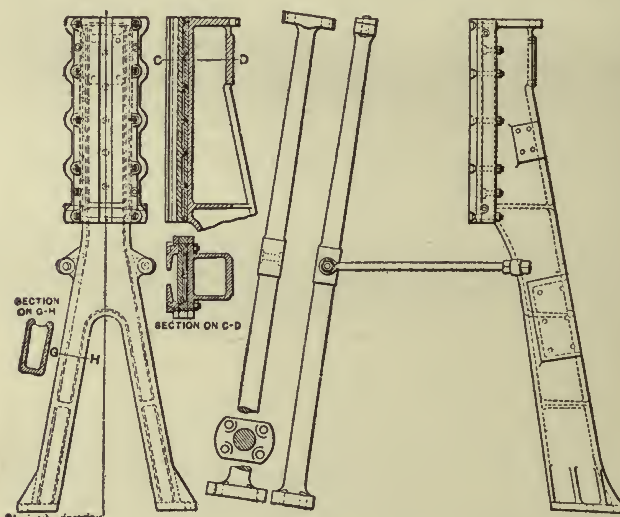

FIG. 6.—INVERTED Y AND CYLINDRICAL COLUMN

city; how do they get in on this engine game?" inquired the 'butter-in' of the class.

"On a marine engine," replied McAndrew, "the guides show the crosshead slippers how to walk the straight and narrow path; if they permitted them to roam around very much there would be trouble. In that respect they differ from the average two-legged guide such as you have met on shore.

"The guides shown in the above sketch attached to the Y-columns are the kind used most extensively for marine

work. When the engine is backing, the pressure on the guides is in the direction opposite from that when it is going ahead, so this pressure is overcome by what are known as 'backing guides,' which are shown in section C-D. The space back of the 'go-ahead' guide is usually fitted for water circulation, whereby the cold sea water flowing through removes the heat caused by the friction on the rubbing surfaces. Marine

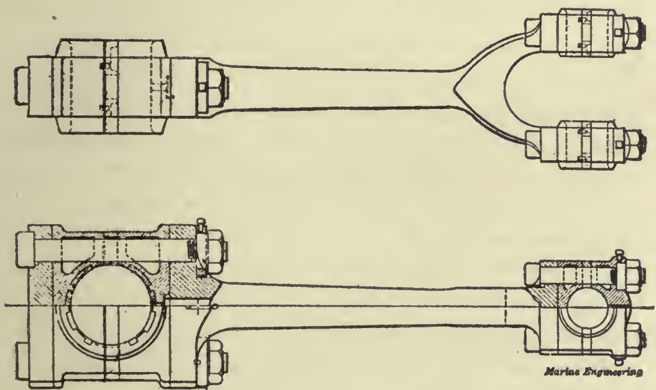

FIG. 7.—CONNECTING ROD

engines back so little of the time that it is seldom necessary to fit the 'backing guides' for water circulation.

"On our way down the engine we next come to the connecting rod, by means of which the up-and-down or reciprocating motion is transformed into a circular or rotary motion by means of the crank. Perhaps Schmidt can tell us the German name for connecting rod."

"Sure!" said Schmidt. "In the old country they call it the 'verbindungstücken.'"

"Gee!" chimed in O'Rourke, "that's about as long as the rod itself!"

"Yes, the word is rather long, and it means, literally, a binding stick, because it binds or connects the crosshead to the crankpin. These rods are almost invariably forged of mild open-hearth steel. Fig. 7 illustrates the type in most general use.

"The upper end, as you will see, is forked to span the crosshead, each side of the fork being fitted with a bearing and the necessary connections to work on the crosshead pin. Solid brass or bronze is used for the bearing metal, as the pressure is too great to permit of the use of soft, anti-friction metal in the bearings. The lower end of the connecting rod is provided with brasses and a cap or binder, all secured by bolts to the T-shaped end of the connecting rod. These brasses are always fitted with 'Babbitt' or other anti-friction metal to reduce the rubbing friction on the crankpin. The white metal surfaces are scored with oil grooves to allow a proper distribution of the lubricating oil. Bearings, such as crosshead and crankpin brasses, necessarily are subject to wear, and consequently must be provided with means of taking up the lost motion. To that end there are spaces between the top and bottom brasses in which are fitted distance pieces of composition and a varying number of strips of thin sheet brass or tin called 'shims,' which, when removed, take up the lost motion due to the wear on the brasses. Later on I will describe to you the method of adjusting crosshead and connecting rod brasses, which constitutes one of the most important of the many duties which befall the marine engineer.

"The crankshaft is the member that actually turns the propeller, and hence is the connection between the producer and the consumer of the power, or the middleman, as they would tell you in business circles."

"He's the guy that causes the high cost of living; but I never heard him called a crank before," suggested O'Rourke.

"Anyhow, the crankshaft is a very important part of an

engine," continued McAndrew. "Nearly all crankshafts are forged of mild open-hearth steel, but some still are built-up forgings of wrought iron. In some high-class marine work the crank for each cylinder is forged in one solid piece, such as shown in Fig. 8.

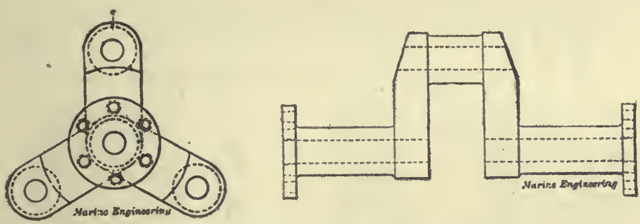

FIG. 8.—SECTION OF FORGED CRANKSHAFT

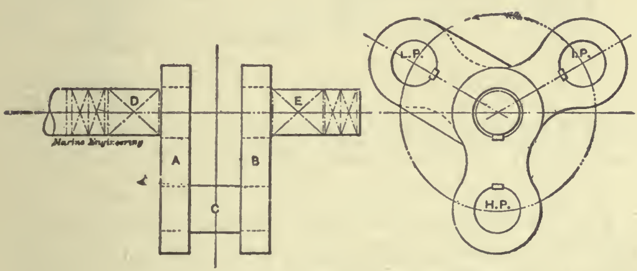

FIG. 9.—SECTION OF BUILT-UP CRANKSHAFT

"The advantage of a crankshaft of this kind is that the sections are interchangeable, so that, for instance, if the low-pressure crankpin should break the high-pressure crank could be put in its place and the engine run compound—that is, if the engine was of the triple-expansion type. The built-up crankshaft is, as its name indicates, composed of several parts, the slabs being shrunk and keyed onto the crank pins and sections of the shaft as shown in Fig. 9."

"Why do some crankshafts have holes in them?" inquired Pierce.

"That is done in high-class work for two principal reasons. One is that it saves weight and the other is that in making large forgings of this kind most of the imperfections, or 'pipes,' as they call them, are liable to be in the central part

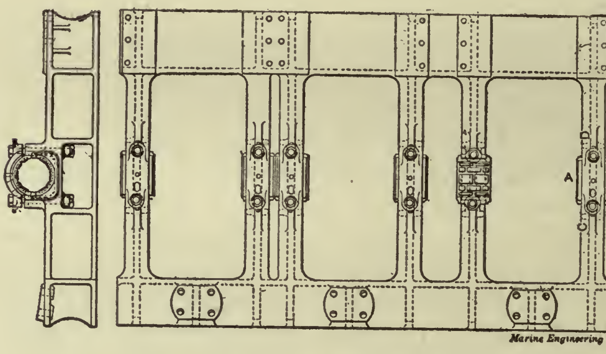

FIG. 10.—BEDPLATE FOR TRIPLE-EXPANSION ENGINE IN ONE CASTING

of the forging. Making the shaft hollow either removes the imperfections or exposes them to the view of the inspector.

"As I told you in the case of the piston rod, a hollow shaft is not stronger than a solid shaft, as many young men imagine; it is simply stronger than a solid shaft containing the same amount of metal. To transmit a twisting strain the metal on the outside of the shaft counts much more than metal at the center. For example, take a shaft 10 inches in diameter; the outer portion of the metal—only .16 inch in thickness—is of as much service in transmitting torsional or twisting strains as the metal 5 inches in diameter at the center of the shaft. Perhaps it will give you a better idea of what I am getting at to state that a shaft 16 inches in diameter, having a 10-inch hole through it, is equal in strength to a solid shaft 15 inches in diameter made of the same kind of metal.

"Further advantages of hollow crank pins are that in case of a pin breaking it could be repaired temporarily by fitting a large bolt through the hole, which would allow the engine to be run slowly at least; the hole through crank pins is also used to advantage in some engines to permit of the fitting of centrifugal oiling devices.

"The bed-plate is the part of the engine which supports the weight of the entire structure, and also forms the seating for

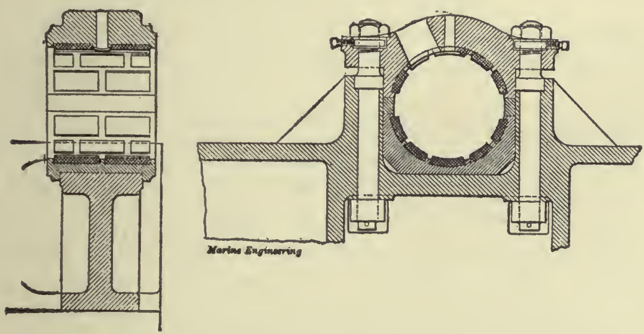

FIG. 11.—DETAILS OF BEDPLATE IN FIG. 10. SECTIONS SHOWING MAIN PILLOW BLOCK

the crankshaft or main bearings. They are usually made of cast iron and sometimes of cast steel, and consist of a series of athwartship girders, one under each crankshaft bearing, all being joined by fore-and-aft girders, one on each side. Naturally, they are made as heavy and substantial as possible. The bed-plate is secured to the foundation, an integral part of the ship's structure, by means of holding-down bolts. Fig. 10 will show you an ordinary type of bed-plate and Fig. 11 a main bearing, or 'pillow block,' as it is sometimes called.

"The main bearing shown in this sketch is such as used for small engines. On larger engines the bottom brass and the cap or binder, as the top bearing is called, are usually cored to

allow for the circulation of sea water in order to prevent the bearing from becoming unduly heated when the engine is run at full speed. All main bearings are lined with Babbitt or other anti-friction metal to reduce the friction."

CHAPTER X

Valves and Valve Gear

"Having gone over the principal parts of the engine, we will now take up some of the minor parts, the principal one of which is the valve gear.

"It is highly important to allow the steam to enter the cylinder at the right time, and it is equally as important to let it out at the right time. These operations must necessarily be performed automatically. The story is told that in the first engine built by James Watt, which was, of course, a very crude affair, he had not progressed far enough in his design to have the valve operated by the engine itself, and, in consequence, a boy was employed to lift the valve and close it at about as near the proper time as his limited training and judgment would allow. Evidently tiring of such monotonous employment, and being of an ingenious turn of mind, he noticed that a certain part of the engine mechanism had about the same motion which he imparted to the valve and at about the same time. Consequently, as the story goes, he tied a stout piece of cord to the valve lever and connected it to the part of the engine which had the coincident motion, whereupon the valve was actuated automatically, and the boy was found by his employer out in the yard playing marbles, civilization having not advanced sufficiently far at that remote period to permit of the youngster indulging in the more scientific game of shooting craps.

"That boy unconsciously formed the first valve gear ever put on an engine, but since his time there has been consider-

able improvement in the method of actuating valves. Before describing any methods for moving the valve, you had first better be given an idea of the valve itself. There are a number of different kinds of valves used on stationary engines, but for marine engines there is practically but one type used, and that is known as the slide valve.

"There are two principal types of slide valve: the flat D and the piston valve. The simplest kind of a flat D slide valve is like Fig. 12.

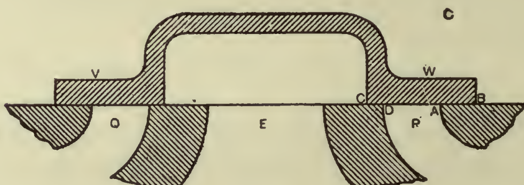

FIG. 12.—PLAIN SLIDE VALVE, MID-POSITION

"This valve, by sliding back and forth over the valve seat, alternately admits and releases steam to and from the cylinder which drives the piston up and down. In Fig. 12 the valve is shown in what is known as its mid-position. The amount which the valve overlaps the steam port in this position, *A B,* is known as the 'lap' of the valve, and you must fix that in your memory, as it is frequently referred to by all marine engineers. There are two kinds of lap, as you will notice that on the inside of the valve it also extends over the port the distance *C D.* The outside lap, *A B,* is known as the 'steam lap,' and the inside lap, *C D,* is the 'exhaust lap.'

"In Fig. 13 the valve is shown at the end of its stroke, and you will notice that the valve has opened one of the steam ports on the outside a distance, *A B;* this is known as 'lead,' and there are two kinds of lead also; the outside, or

A B, being known as the 'steam lead,' and the inside, or *C D*, being known as the 'exhaust lead.'"

"Chief, that sounds like horse race dope, the kind I used to hear down at Brighton Beach," said O'Rourke. "I suppose you will be telling us next that the high-pressure valve is in the lead—one lap ahead of the low-pressure."

"No doubt, young man, you know more about horse race dope than you do of anything else; but this is no place for such silly remarks," tartly rejoined McAndrew.

"Why does a valve have this lap?" inquired Nelson.

"There is some sense to a question like that," said the instructor. "Lap is given to a valve so that the steam can be

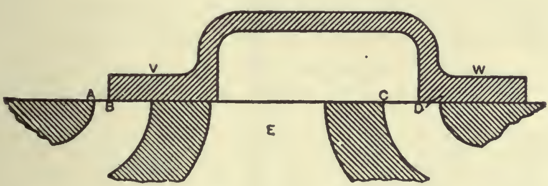

FIG. 13.—PLAIN SLIDE VALVE, POSITION FOR END OF STROKE

cut off at a portion of the stroke and be allowed to expand in the cylinder. If the valve was made the same over-all length as the distance between the outer edges of the two steam ports, live steam from the boiler would be allowed to follow the piston nearly the entire stroke, and we would gain nothing from the expansive effect of the steam.

"As the piston nears the end of its stroke, a certain amount of the exhausting steam in the end of the cylinder towards which the piston is traveling is retained, and as it cannot escape it is compressed and forms a cushion, which overcomes the momentum of the piston, rod, etc. As this is generally insufficient to overcome so much momentum, the live steam for the return stroke is admitted prior to the time when the

piston starts on its return. The amount the steam valve is open at the very commencement of the return stroke is, as before stated, known as 'lead,' the purpose of which is to aid in quickly overcoming the momentum of the moving parts and to start the piston back quickly on its return.

"Some old-fashioned simple and compound engines are furnished with a cut-off valve separate, and working upon the back of the regular valve in order to get a sufficient amount of expansion of the steam, but in triple or quadruple-expansion engines we do not need to cut off closely in the high-pressure cylinder, as there are three or four cylinders in which the expansion may take place. A double-ported slide valve is one used when it is desired to get a very large port opening for a comparatively short valve travel; it is practically one valve within another, and there are two steam ports instead of one in the valve seat, the steam for the outside ports entering over the ends of the valve and the steam for the inner ports coming through passageways in the sides of the valve. On nearly all large cylinders it is found necessary to use these double-ported valves, or otherwise the valve travel would be entirely too great.

"The great disadvantage in using the flat slide valve is the large amount of power consumed in overcoming the friction between the valve and its seat. For instance, a slide valve of ordinary size would be, perhaps, 30 inches long by 42 inches wide, a flat surface of 1,260 square inches. At only 40 pounds pressure per square inch in the steam chest there would be a pressure of over 50,000 pounds pressing the valve against the valve seat. You can readily imagine that the friction caused by moving iron against iron with such a load as that is enormous. Therefore, flat slide valves are not used to any great extent nowadays except in small engines, and then only for the low-pressure cylinder, where the initial pressure of the steam entering the cylinder is usually not over 5 to 10 pounds.

"Some wise old-timer, to get away from using flat slide valves, conceived the idea of wrapping up his slide valve into

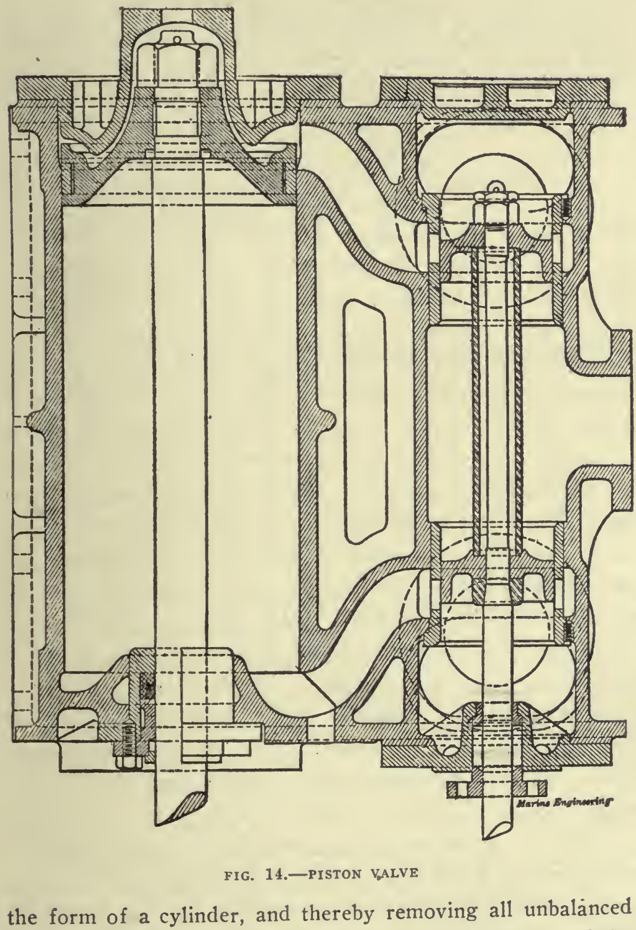

FIG. 14.—PISTON VALVE

the form of a cylinder, and thereby removing all unbalanced pressure from the valve while retaining the advantages of the slide valve. Its essential features are two pistons or heads

joined by an intermediate distance piece, all being held in place on the valve stem by nuts and washers, as shown in Fig. 14.

"The steam is admitted and exhausted to and from the cylinder by the edges of the valve in precisely the same manner as the flat slide valve. The only disadvantage is the excessive clearance as compared with the flat valve."

"What's clearance, Chief?" remarked Nelson.

"The clearance space in an engine is the volume of the steam ports and passageways between the piston and the bottom and top heads of the cylinder. It would never do to have the moving piston strike the head, either at the bottom or top, for if it did it would knock them off. Consequently there is usually a space of about ¼ inch at the top and ⅜ inch at the bottom, always more at the bottom to allow for the bearings wearing down. These distances are known as the linear clearances, while the entire volume of the space between the piston at the end of its stroke and the cylinder head, plus the volume of the steam passageways, is known as the volumetric clearance. Naturally, as the ports have to reach clear around the piston valve, there is more of this volumetric clearance for this type than there is for a flat valve which lays close up to the cylinder. In modern engine designs this volume is considerably decreased by making the ports straight instead of curved, as shown in the sketch.

"Piston valves can be kept tighter than flat slide valves, for the reason that it is usual to fit the two pistons composing the valve with packing rings similar to those used for the main pistons.

"We have looked into the principal kinds of valves used on marine engines and know what functions they perform, now we want to know what kind of apparatus it is that moves the valves. There are three principal types of operating gear used on marine engines, known by the names of the inventors, respectively, as 'Stephenson,' 'Joy' and 'Marshall.'

"The Stephenson gear is probably used on over 90 percent of the marine engines in use. If ship's engines had to travel in one direction only, the valve mechanism would be comparatively simple, but engines of this kind, as well as those on locomotives, have to be reversed frequently, so it is necessary to have the valve gear designed so that it can go either ahead or back.

"This condition was quite readily solved by Stephenson, one of the first engineers, when he invented his link gear. In this mechanism the fundamental motion is taken from the

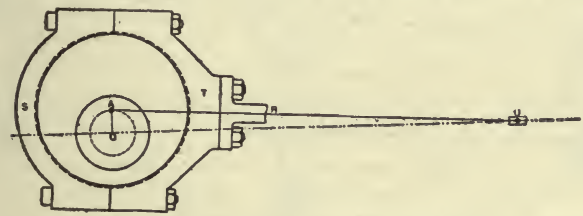

FIG. 15.—PLAIN ECCENTRIC, SKELETON MOTION

crankshaft by means of eccentrics keyed to the shaft. Perhaps O'Rourke can tell us the difference between an eccentric and a crank."

"That's easy," replied the ever-ready. "If a rich man does queer things he is an eccentric, but if a poor man does the same stunts everybody calls him a crank."

"Well, that brings out the idea, anyhow," continued McAndrew. "There is in reality very little theoretical difference between an engine eccentric and a crank, as an eccentric is practically a self-contained crank. The term 'eccentric' means literally 'having different centers,' whereas 'concentric' means having the same centers. Hence it is that the center of the sheave, forming the eccentric, is set off from the center of the shaft upon which it operates, a distance which is known as the 'eccentricity' or 'throw.' The following will illustrate the idea of the eccentric:

"The distance $A\ C$, Fig. 15, between the center of the shaft and that of the sheave is the throw, and the up-and-down motion imparted to the valve, or the valve travel, as it is known, is double this throw. Around the eccentric sheave is fitted a band or strap, as it is termed, made in halves and bolted together, which strap is bolted to the heel of the eccentric rod. This rod is forked at its upper end and spans one end of the

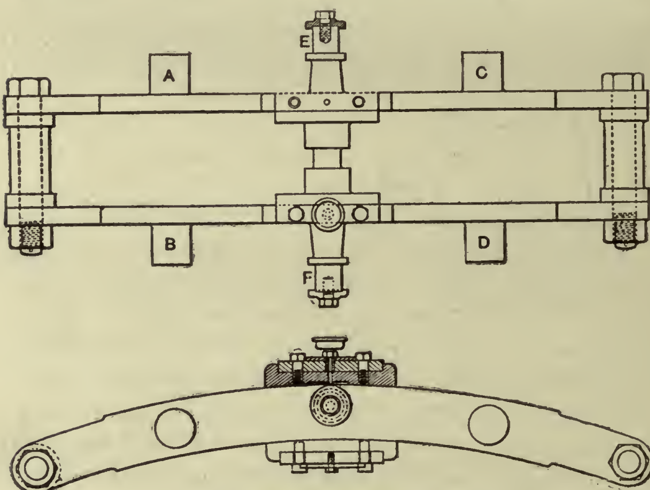

FIG. 16.—STEPHENSON DOUBLE BAR LINK

link. There are two eccentrics and all the necessary connections for each cylinder, one known as the 'go-ahead' and the other as the 'backing' eccentric. The go-ahead eccentric rod connects with one end of the link and the backing eccentric rod with the other end.

"Almost all links for large engines are of the double-bar type; that is, they are built up of two parallel steel bars, each forming the arc of a circle, the radius of which is equal to the distance between the center of the eccentric sheave and the center line of the bars.

"You will notice the mechanism in the center of the link. That is known as the link block, and it forms the connection between the link and the valve stem. In operation the links are thrown from one side to the other, so that the link block is actuated by either the go-ahead eccentric or the backing eccentric, as may be desired, by placing the link block in line with either of these eccentric rods.

"Eccentric sheaves are always made of cast iron, in two unequal halves, in order to bring the joint between them on the center line of the shaft, so that they can be readily removed.

"The eccentric straps which ride on the sheaves are also made in halves, bolted together, and are usually of cast iron or cast steel, lined with white metal in order to reduce the friction.

"Eccentric rods and link bars are usually made of wrought steel of the best quality. The link blocks are usually of forged steel, fitted with composition wearing pieces where they rub on the link bars. Sometimes they are cast entirely of bronze.

"To reverse an engine, that is, to change it from the ahead motion to the backing motion, or *vice versa,* there is provided a rock shaft, which extends along the engine columns, and to which it is supported in brackets. On this rock shaft there is secured for the valve gear of each cylinder a lever, or reversing arm, as it is called. This arm connects to the valve gear links by suspension or bridle rods, as they are sometimes called. This rock shaft on small engines is operated by hand through the medium of a long lever, or in some cases by a large hand-wheel and screw. However, this means is not practicable for larger engines, as it would require more power than a man could apply. Hence all large marine engines are fitted with what is known as a reversing engine, which consists of a steam cylinder, the piston rod of which is connected

by means of links to the reverse arm on the rock shaft. Fig. 17 will show you details of an ordinary reversing engine.

"The valve of this steam cylinder is controlled by what is termed a 'floating lever,' the initial motion being given it by means of the hand reversing lever located at the working platform. A small slide valve of either the flat slide or the

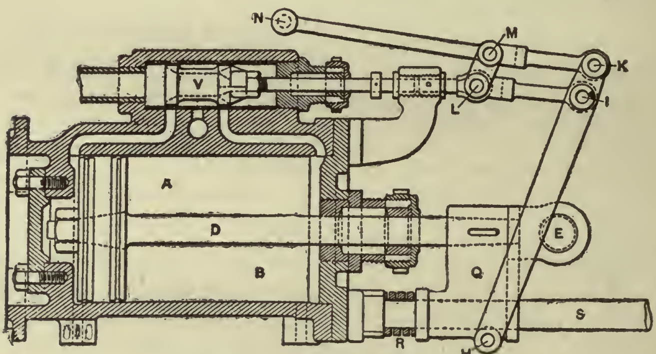

FIG. 17.—FLOATING LEVER REVERSE GEAR

piston slide type controls the admission of the steam to the cylinder. Unless the lever at the working platform is handled by an experienced man, the piston is liable to go forward or backward with a rush, causing the gear to slam. To avoid any damage being done it is customary to fit strong spiral springs at each end of the crosshead guide rod to prevent slamming."

CHAPTER XI

Engine Fittings

"As we look into the fittings which go on a boiler we should also pay some attention to what are known as engine fittings.

"The principal of these is the throttle valve, by means of which the engine is started or stopped at will. It is customary to bolt the throttle direct to the high-pressure valve chest, and to operate it by means of a lever and rods from the working platform. The most generally used type of throttle valve is known as the double-beat valve, the general principles of which are shown in Fig. 18.

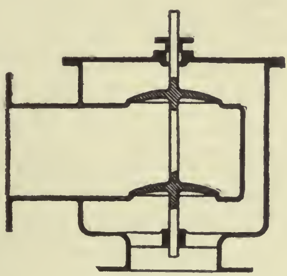

FIG. 18.—DOUBLE BEAT POPPET VALVE

"This is really two valves in one, the steam entering through two openings in the valve casing. The two disks are worked on one stem, the upper disk being made slightly larger than the lower one, so that the tendency is always to close the valve. However, this difference in the load on the two disks is so slight that it can readily be overcome by means of the throttle-working lever. This lever works on a notched quadrant, and

it is held in position by means of a spring latch. In practical working of a throttle you will find that it only needs to be opened a very slight amount in order to work the engine 'to bells,' as it is termed.

"Right here it may be well to inform you that a valve does not have to be opened very far to secure a full opening, or to have it 'wide open,' as the term is. A little figuring will illustrate the idea. For example, if you are using a throttle 10 inches in diameter, its total area is 10 by 10 by .7854 = 78.54 square inches. That is, to find the area of a circle you multiply the diameter by itself, or square it, as the mathematicians would tell you, and then multiply that product by the constant .7854. To find the circumference of a circle you multiply the diameter by the constant 3.1416. This last constant is known as 'pi'; now don't be alarmed, O'Rourke, for that is not the kind you eat, it is simply the Greek letter that is selected to represent the ratio between the diameter and circumference of a circle. The circumference of a 10-inch circle is 31.416 inches. Dividing 78.54, the area in square inches, by the length of the circumference, 31.416 inches, you will find the answer to be 2.5. In other words, a 10-inch throttle valve has to be opened only 2½ inches to be wide open. You should also note that 2½ is just one-fourth of 10, and bearing in mind that the ratio between the circumference and diameter of all circles is the same, you will see that any valve has to be raised only a distance equal to one-quarter its diameter to be 'wide open.'

"Most valves are designed to allow a larger opening, but you will see from the illustration that it is not necessary to jam a valve open as far as it will go in order to get the full area through it."

"Isn't it possible to get a triple-expansion engine stuck on a center?" asked Pierce.

"Yes, it is not only possible but it occurs quite frequently,"

answered McAndrew. "To avoid trouble of this kind all compound and triple-expansion engines are fitted with what are termed 'pass-over valves.'"

"That must be a Jew valve!" suggested O'Rourke.

"This is hardly that kind of a valve," continued the instructor. "The necessity for such a valve occurs when the high-pressure crank is on the top or bottom center, a condition which generally arises at the most inopportune times, such as working the vessel into a dock. However, by quickly opening the pass-over valve, a small stop or slide valve, live steam is admitted into the intermediate valve chest, which starts the intermediate piston in motion and pulls the high-pressure crankpin over the center. The hand-wheel or lever for controlling the pass-over valve is always located at the working platform within convenient reach of the man operating the engine."

"Why are drain valves necessary?" asked Schmidt.

"Because steam when entering a cold cylinder or valve chest is condensed into water, which, if not allowed to drain off, would cause a water hammer and might break a cylinder head. Drain valves are located at the bottom of each valve chest and cylinder at the lowest points. Sometimes they are operated by means of an extension rod and a hand-wheel at the side of the cylinder, but more often by means of shafts and levers located close up to the working levers, so that the man operating the engine can open or close the drain from any cylinder without leaving his position.

"Relief valves are located on each valve chest and at the top and bottom of each cylinder. These are, in reality, small safety valves, similar to those used on boilers, and are for the purpose of automatically relieving any excess pressure, either of steam or water, mostly that caused by water, in the cylinders."

"What is the use of a turning engine?" inquired Nelson.

"That's easy," volunteered O'Rourke. "It's to keep us horny-handed sons of toil out in the fire-room from breaking our backs by jacking the old engine over every day!"

"Judging from some firemen I have had with me," replied McAndrew, looking straight at O'Rourke, "working the turning gear is about the only real work you can get out of them while the vessel is in port.

"Turning-engines are not usually fitted on engines of less than 3,000 horsepower, as it is much simpler to have the ordinary hand gear, which usually consists of a large worm-wheel secured to the crankshaft just aft of the engine bed-plate; a small, vertical or inclined shaft pivoted at the bottom works the worm, which meshes with the main turning wheel, the shaft being operated by a ratchet lever. If steam power is used it is usual to drive the worm-wheel by means of one or two small cylinders, the whole apparatus being so geared that it takes hundreds of revolutions of the small engine to turn the main engine over once."

"Why do you have to turn the main engine over when steam is not on it?" asked Pierce.

"It is quite often necessary to do so when making adjustments to the crankpin brasses, in order to get the particular crank on the top center; sometimes it is necessary to jack the main engine over while adjusting the valve gear. All engines in which metallic packing is used for the rods should be jacked at least once each day, in order to prevent rough places being formed on the polished rods from standing too long in contact with the packing at any particular point of the stroke.

"Leaving the main engine and looking aft, the first thing of importance we see is what is known as the 'thrust bearing,' a most important element in steam machinery, as it is by means of this piece of mechanism that all of the driving power of the propeller is transmitted to the ship itself.

"As the propeller revolves in the water it has the same ten-

dency to advance that a screw has in a piece of wood, and it is this pushing effect, or thrust, as it is called, which, transmitted through the agency of the shafting and the thrust bearing, drives the ship along. This bearing therefore must be firmly secured to the hull of the ship, and must be so designed as not to become overheated on account of the necessarily large amount of friction on the bearing surfaces. That part of the shafting upon which the thrust bearing is located is known as the 'thrust shaft,' and it is usually made short in length in order to facilitate its removal from the ship when it becomes necessary, as may happen, that it has to be placed in a lathe for the purpose of removing the scores from the bearing surfaces. On this thrust shaft are a number of solid rings or collars, which fit between what are known as 'horseshoe collars,' and which are supported on rods on each side of the bearing, each being provided with two adjusting nuts on the rods, so that each individual horseshoe may be adjusted to bear a proportionate amount of the thrust of the shaft. The bearing faces of these collars are lined with white metal, so as to reduce the friction to a minimum. The bottom of the bearing usually forms a rectangular tank or trough, which is filled with oil so that the collars on the shaft revolve in it and carry the lubricant to the bearing surfaces. To keep the bearing cool it is customary to fit a flat coil of pipe in the bottom of the oil reservoir, and to connect this coil to the water circulating system. The best thrusts also have separate water pipe connections to each horseshoe collar. Too much attention cannot be given to the thrust bearing, for if it is not properly oiled and cooled a great deal of trouble can arise on account of excessive heating.

"Just aft of the thrust shaft, the main or 'line shafting' extends to what is known as the 'tail shaft,' the last portion of the propeller shafting. This line shafting is known as the intermediate shaft, and is made in one, two or three sections,

according to the length of the vessel. All lengths of the shafting proper are made of the best quality of wrought steel, and they should be carefully forged and inspected, as the breaking of any part of this important connection between the main engine and the propeller totally cripples the ship if she is of the single-screw type. It is customary to connect the several

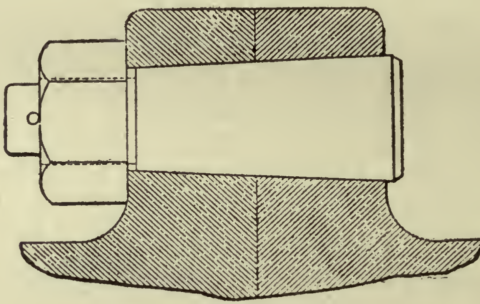

FIG. 19.—DETAIL OF FLANGE COUPLING AND BOLT

sections of the shafting together by means of what are known as flanged couplings and tapered bolts, as shown in Fig. 19.

"The bolts are made tapered for convenience in backing them out whenever it becomes necessary to remove a section of the shaft.

"Each section of the intermediate shafting is usually supported on two bearings, which rest on suitable foundations of plates and angles built up from the frames of the ship. These bearings probably have more names than any other part of the steam machinery. Different people refer to them as 'spring bearings,' 'pillow blocks,' 'tunnel bearings,' 'steady bearings' and plain bearings. However, no matter what they are called their function is a very simple one, namely, that of supporting the weight of the shaft and keeping it in alinement. With such simple duties to perform, it is customary to fit the bottom with a brass, or to line it with white metal.

The top of the bearing serves no other purpose than to keep the dirt out of it, and to support oil cups or compression cups containing grease for lubricating purposes.

"Inexperienced oilers, like O'Rourke will probably be, pay a great deal of attention to spring bearings, but the old timers give them a familiar slap in passing, as they know that bearings of this kind seldom give trouble from overheating.

"In single-screw vessels the tail shaft, or propeller shaft, passes through what is known as the 'stern tube,' a heavy cylindrical iron or steel casting extending from the after bulkhead of the shaft alley to the eye of the stern post. It is advisable, and also customary, to increase the diameter of the tail shaft over that of the intermediate shafting, as where it passes through the stern bearing it is not possible to inspect it often, and being constantly immersed in salt water it may become badly corroded. To provide against this corrosion the tail shaft is usually encased in composition sleeves shrunk on the shaft by heating the casing before it is slipped in place. By carefully soldering the ends and the joints between the sections of the casing, the water is usually kept out, but unless the soldering is well done the water is liable to leak in and cause havoc to the shaft.

"At the forward and after ends of the stern tube, bearings are formed of composition castings containing dovetailed grooves. In these grooves are strips of lignum-vitæ, a tropical wood and about the hardest that grows. The bearing surface should be on the end of the grain, and the strips should be well soaked in oil before being driven into place, as the water which circulates around the shaft is the only lubricant it receives. At the inboard end of the stern tube there is a stuffing-box packed with square hemp or flax packing, a job which can only be attended to while the vessel is in the dry dock. There is usually fitted a small cock and a pipe leading to the water space, by means of which a small stream of water

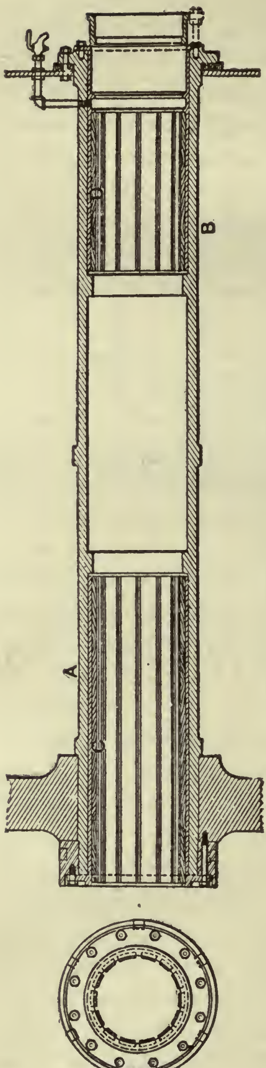

FIG. 20.—STERN TUBE AND BEARING

is allowed to trickle on the stuffing-box and its gland in order to keep them cool. This also allows a circulation of the water in the stern tube.

"In sandy or muddy water the lignum-vitæ in the bearings is found to cut out quickly, and in some vessels it is customary to fit a stuffing-box at the after end of the after bearing and to line the stern bearing with white metal. Lubrication is furnished to such a bearing by means of an oil cup or compression grease cup located above the waterline in an accessible position.

"Fig. 20 will show the usual form of stern tube, bearings, etc., used on single-screw vessels."

"Chief," interrupted O'Rourke, "you can't go much further aft without telling us about propellers, can you?"

"For once, O'Rourke, you are right, as that is certainly the next step.

"The subject of propellers is one of the most interesting connected with marine engineering. Volumes have been written about them, and nearly

every engineer of any standing in the business has, at one time or another in his career, attempted to invent a new kind that would be far superior to any other propeller ever made. The Patent Office contains about as many propeller designs as there are ships on the seas. About one of these designs in ten thousand is of any practical use, so let me warn you young men never to let your fancies run to the idea that you can invent a propeller.

"The whole science of propeller designing is based on a process of evolution. Do you know what 'evolution' means, O'Rourke?"

"Sure!" said he of Irish extraction. "That means that man is descended from a monkey."

"You have the idea all right, and the modern propeller has about the same relation to the original propeller as a man bears to his original, in accordance to the theory of a certain philosopher named Darwin.

"When propellers were first invented, the idea was that they should be as large as it was possible to have them. A story is told of an old-time coasting steamer fitted with an engine of five or six hundred horsepower driving a four-bladed propeller about 15 feet in diameter. She was ambling up the coast one day at a 6-knot clip when the propeller struck a log; whereafter, as the story goes, she immediately increased her speed to 7 knots. On examination it was found that one of the blades had been broken off, a fact which immediately started the theory that a three-bladed propeller was the proper thing to use. As a matter of fact, the increased speed was undoubtedly due to the reduction in area of an excessively large propeller.

"The best designed propellers of to-day are those built in accordance with data derived from propellers which have been in use. Step by step they have been improved upon until it seems that we have to-day reached a point where but little more

improvement can be made. The crude propellers used on the first screw steamers and all propellers used since that time have been useful in developing the modern propeller, as it has been from actual experience, and after very expensive experience, too, that perfection in propeller design has been gradually approached.

"The results of all these years of experimenting have evolved a standard wheel with uniform pitch and blades elliptical in shape set at right angles to the shaft axis, or slightly raked aft from the perpendicular, according to the individual fancy. The great majority of propellers are now four-bladed, a small portion of them three-bladed, and occasionally we see a two-bladed propeller on an auxiliary vessel.

"Propellers, small in diameter, are almost invariably made solid; that is, the hub and blades are cast in one piece, such as shown in Fig. 21.

"Larger propellers are of the 'built-up' type; that is, the blades and hub are cast separately and the blades are flanged and bolted to the hub. The advantages of this type are that in case any of the blades are broken they can be replaced without throwing away the entire wheel, and, further, that by slotting the holes in the blade flanges the pitch can be altered if deemed necessary."

"What material is best for propellers?" inquired Nelson.

"That depends on how much money you have," replied the chief. "In fact it is something like buying underclothes. A poor man buys cotton and it serves the purpose; a man of moderate means buys woolen—that serves the purpose better; a rich man would buy silk, and that is better than any of the others.

"With propellers, cast iron serves the purpose and is cheap; cast steel is stronger and costs a little more; bronze is

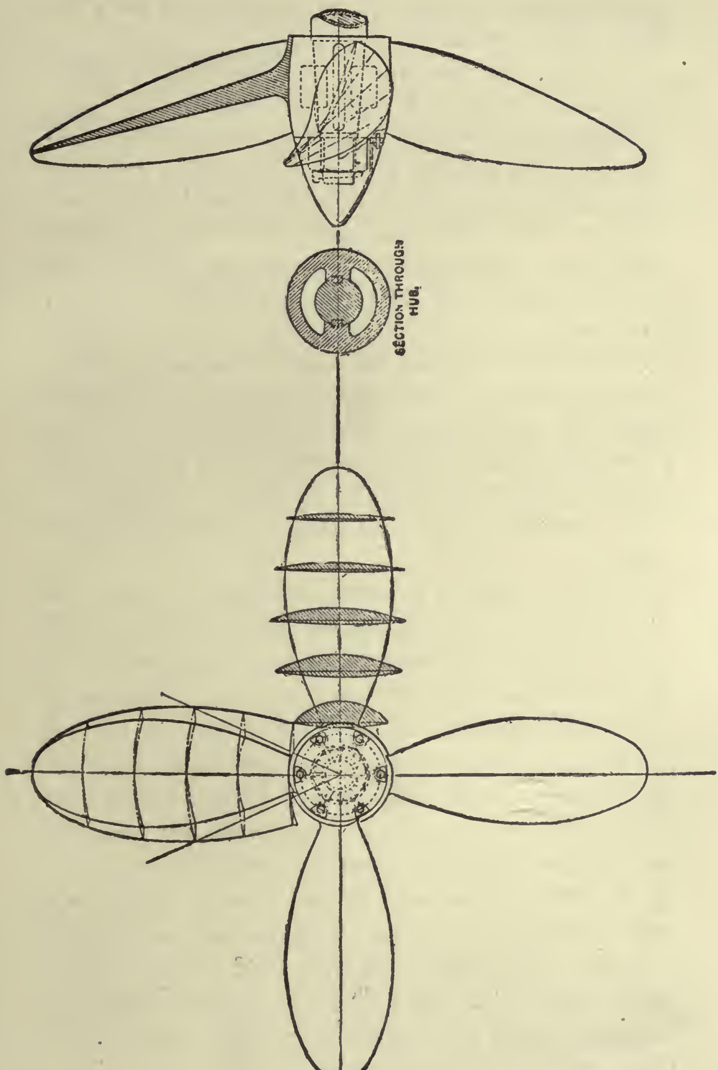

FIG. 21.—SCREW PROPELLER, BLADES CAST WITH HUB

stronger, smoother and lasts longer, but costs much more than either of the other materials."

"I think Schmidt must wear a cast iron undershirt, judging from the rust he has on it," suggested O'Rourke.

"If shipowners but knew it, polished manganese bronze or other high-class materials would be much cheaper in the end than cast iron or cast steel. A screw driven into wood encounters considerable friction, and you will be surprised to learn that the screw-propeller driven through the water also encounters a great deal of friction. Experiments have shown that from 10 to 20 percent of the total power of the engine is consumed in overcoming the friction of the screw. Hence it pays to have the blades made as smooth as possible to reduce this frictional loss. Recent experiments of rubbing graphite on the blade surfaces demonstrate that an appreciable amount of friction is reduced by means of that lubricant."

"What do they mean by the pitch of a propeller?" asked Pierce.

"McAndrew picked up a bolt that was lying on a bench, and said: "I hold this nut rigid in my hand and turn the bolt head one complete revolution; you will see that the end of the bolt has advanced about 1/16 inch out of the nut—that is what is called the 'pitch' of the thread on the bolt. So with propellers, the pitch is the distance the ship should be driven ahead by one revolution of the screw if it was driven through a solid. But water is not solid by any means, and hence the ship does not advance the distance it should; the difference between what it does advance and what it would advance in a solid is called the 'slip.' This term is always expressed in percentage; for example, if the pitch of the screw is 20 feet, and the ship is driven ahead only 17 feet at one revolution of the engine, the slip is 3 feet, and there would be said to be a 15 percent slip, as 3 is 15 percent of 20."

"How do you tell whether a propeller is right or left-handed?" asked Schmidt.

"The best way to tell that is to imagine yourself in the bottom of the dry dock looking forward at the propeller. When the screw is driving the ship ahead and it turns in a direction corresponding to the motion of the hands of a watch it is called right-handed. If in the opposite direction then it is left-handed.

"The driving face of a blade is not, as you might imagine, the forward side, but the after side, as it is that side which acts on the water; therefore the back of a blade is its forward side."

"That sounds Irish," said Schmidt, glancing at O'Rourke.

"The area of a propeller, sometimes called the helicoidal area, is the sum of the actual areas of all of its blades.

"Later on I will try to show you how to calculate the pitch of a propeller by measuring the wheel in position."

CHAPTER XII

Condensers, Air and Circulating Pumps

The repairs to the *Tuscarora* were rapidly nearing completion; the new boilers were in place, much of the connecting piping had been gotten out and the end of the job was in sight. The students of the "Floating School" had not lost interest in their voluntary work, although their regular duties were now much harder than at the commencement of the repairs. McAndrew had looked for his pupils to slacken in their interest in his lectures, but no one had missed a single evening which he had devoted to their instruction. In consequence he had determined to carry the course through for them, and on this particular evening in early March he opened his remarks by saying:

"Well, boys, this work I know is rather dry to you, but later on we will get into something more interesting to you. I propose to cover all the principal parts of marine machinery by these lectures, and then to give you some practical questions on the subject and to show you how various problems are worked out.

"Up to date I have tried to instruct you in a general way as to how steam is generated and how it is utilized to produce power. We now come to the part where, having used the steam, we must get rid of it. This is a step second only in importance to generating the steam. We have seen that by applying heat to water in the boiler steam is formed; the condenser serves directly the opposite purpose, for therein the heat is taken out of the steam and it returns to its original state—water. Some people look at the condensers as if there were

something mystifying about its action, but the process of condensation is simplicity itself. The very atmosphere we breathe acts as a condenser, for you no doubt have noticed how readily steam escaping from an exhaust pipe is turned into water simply by contact with the air, and especially is this noticeable on a cold day.

"You might think that in the steam as it leaves the engine there is but little heat left, and as a matter of fact the temperature is only about 110 degrees F.; but you must remember the first principles and realize that the temperature as shown by the thermometer is only the sensible heat. Do not forget that when the water was transformed into steam it took about 934 heat units, known as the latent heat, to bring about this change of state. To turn the steam into water again this latent heat must be taken out in order to accomplish the change, and, approximately speaking, there are 1,000 heat units per pound of steam to be carried off by the cooling water. Herein lies one of the great wastes of any steam plant, and unless the exhaust steam can be utilized for heating the feed water, or for heating buildings in the case of shore plants, there is no way yet devised to prevent it."

"Chief," interrupted Pierce, "I don't understand how this exhaust steam can have so low a temperature as 110 degrees F., when you told us that steam did not form until the thermometer stood at 212 degrees F."

"I see," replied the instructor, "that you did not grasp the idea of water boiling at different temperatures according to the pressure it is under. It is true that under atmospheric pressure it does not form steam until 212 degrees, but as the pressure is reduced the boiling point is lowered accordingly. Steam leaving the low-pressure cylinder of an engine is at an absolute pressure of only a pound or two corresponding to a vacuum of 26 or 27 inches, and if you were to boil water in such a vacuum you would find that steam forms at a tem-

perature of approximately 110 degrees. Hence it is that the exhaust steam has such a low temperature.

"Fortunately the best medium for condensing steam is cool water, so on shipboard the supply of cooling water is, of course, close at hand. The condenser, as the apparatus for bringing about the transformation from steam to water is termed, is made in two principal types for marine purposes. The jet condenser consists of a large cylindrical casting into which the exhaust steam passes, and where it comes in contact with jets of water which transform or condense the steam to water. As the condensing water is used in such large quantities it must be pumped overboard, together with the water of condensation. For vessels sailing on fresh water such a device is cheap, economical and highly efficient, but for vessels plying in salt water where the condensed exhaust steam must be used over and over again for boiler feed, jet condensation is absolutely useless. Hence we have what is known as the surface condenser, wherein the steam does not come in direct contact with the circulating or cooling water.

"Surface condensers are made either cylindrical or rectangular in section, according to the space which they are to occupy. When they are built in the engine framing, as most frequently happens in merchant vessels, they usually have a cylindrical top with flat sides and bottom, strongly ribbed to prevent collapse from the external pressure of the atmosphere. At each end of the condenser there is what is known as a water chest for the entrance and exit of the circulating water. The greater portion of the interior of the condenser is filled with small brass tubes, usually 5/8 inch outside diameter, running lengthwise, and fitting into what are known as tube sheets, one at each end of the condenser. These tubes are spaced very closely together, and through them flows the cool sea water. The exhaust steam as it enters the condenser thus comes in direct contact with the outer surface of these small

tubes and is quite readily transformed into water. In order to prevent the steam from striking the tubes in one spot directly opposite the exhaust pipe, it is customary to fit a perforated baffle plate opposite the opening for the exhaust, which baffle plate scatters or deflects the steam along the entire length of the tubes. It is, of course, highly essential that the condenser

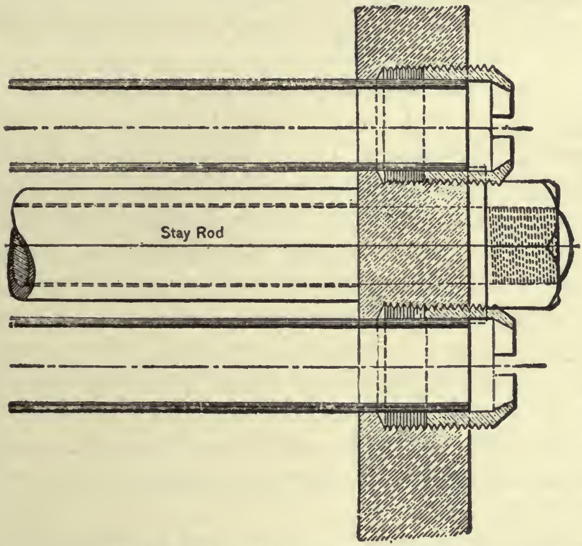

FIG. 22.—FERRULES AND TUBE PACKING IN SURFACE CONDENSER

be kept as tight as possible, for if there are any leaks the salt circulating water will be forced into the body of the condenser, where it will mix in with the condensed steam and find its way into the boilers. Hence great care must be exercised in packing the ends of the innumerable small tubes. Fig. 22 will show you how these tube ends are made tight.

"Holes are tapped in the tube sheets into which are screwed small glands known as ferrules, and the packing space is usually filled with corset lacing."

"Gee!" exclaimed O'Rourke, "they ought to carry lots of girls on ships to furnish all that corset lacing."

"You will notice," continued McAndrew, "that the ends of these glands or ferrules are beaded over slightly. That serves the purpose of preventing the tubes from crawling out of place on account of the contraction and expansion due to the varying temperatures to which these long, slender metal tubes are subjected. It also allows them to expand without starting to leak, as would otherwise be the case.

"If condenser shells are cylindrical in shape it is usual to make them from rolled steel plate, but if they are of rectangular section they are almost invariably made of cast iron. The tube sheets are always made of composition. The tubes themselves are made either of brass or Muntz metal, usually coated outside and inside with tin, although many designers do not think that this tinning process is now necessary. At the water ends, particularly, where iron and brass are in such close proximity, it is very important to see that a sufficient amount of zinc plates is suspended in the water to prevent galvanic action. Some careful engineers also have zinc plates fitted in baskets in the fresh-water side of the condenser for the same purpose, although these are not so essential there as in the water chests.

"This evening as I was coming into the engine room I noticed you boys looking around the main condenser, so I supposed you were trying to study its connections."

"Yes," replied O'Rourke, "Schmidt was trying to find how the air got into the air pump when there is only steam goes into the condenser."

"I suppose," replied McAndrew, "that the air gets in the air pump just about the same way that water gets in the milk we buy at the corner grocery—it's put in. The term 'air pump' is really a misnomer; to be sure, there is a small amount of air gets into the condenser with the steam, but the main func-

tion of an air pump is to pump the condenser water out of the condenser, and incidentally any air and vapor that may be there.

"Air pumps on board ships are, as a rule, vertical, and of two general types, connected and independent. By 'connected' we mean that they are worked through the medium of beams from one of the crossheads of the main engine, usually the low pressure. The principal advantages of this arrangement are the certainty of action so long as the engine is running and the economy of operation, as the power is, of course, furnished by the main engine, which is generally of the most economical multiple-expansion type. Its disadvantage is that there is no vacuum while the main engine is not running. This, however, is not great, as the vacuum is produced almost at the first stroke of the main engine.

"An 'independent' air pump is one that is driven by its own steam cylinders; and as a rule this type is uneconomical, as the economy of operation is only equivalent to that of a slow-running simple engine. There is an advantage, of course, in always having a vacuum in the condenser whether the main engine is running or not. Unless an independent air pump is of very good design and kept in good order, there is always a likelihood of its stopping at the most inopportune times. In this they closely resemble a mule who will work along all right until, perhaps, when crossing a railroad track, he will get balky just as a train is coming along."

"Do you start a balky pump the same way that you would start the mule?" inquired Pierce.

"Very much the same," replied McAndrew. "I once had an Irish oiler with me who would occasionally get mad when the air pump stopped, and would strike it on the valve chest with a top-maul. Very frequently the pump would start off immediately on being given that treatment, probably because the jar would start the controlling valve which had stuck. How-

ever, I do not recommend such strenuous treatment of balky pumps, and you had better not let me catch any of you striking pump valves that way on board this ship.

"The air pump itself is usually of the same design, whether operated independently or attached to the main engine. Fig. 23 will show you the type usually adopted for marine work.

"Air pumps are always attached to the very lowest part of the condenser, so that the water of condensation will flow to the pump by gravity. In the sketch you will note that the pump is not unlike any ordinary style of pump for pumping liquids. The valves form the main distinguishing feature. There are, as you will see, three sets of these valves; the ones at the bottom being termed 'foot valves,' those in the piston are known as 'bucket valves,' and the set of valves at the top are 'discharge valves.'

"The method of operation is that as the bucket or piston starts on its upward stroke a vacuum is produced in the pump barrel, which, when it overcomes the vacuum in the condenser, causes the water, air and vapor to rush through the foot valves into the body of the pump. On the down stroke the contents of the pump are in turn discharged through the bucket valves, and on the following up-stroke are forced through the discharge valves at the top, whence they go to the hot well or feed tank. You will notice that the top plate on the pump which contains the discharge valves is not bolted to the pump in this sketch, but is held down by a large spiral spring. This is what is known as a floating top, and it is thus arranged so as to allow the ready escape of a large volume or gulp of water which is liable to pass through the pump at any time. Quite often pumps which have not been provided with bucket on a large mass of water which could not escape quickly a floating top have had the top broken by the impact of the enough through the small valves. Most large air pumps are

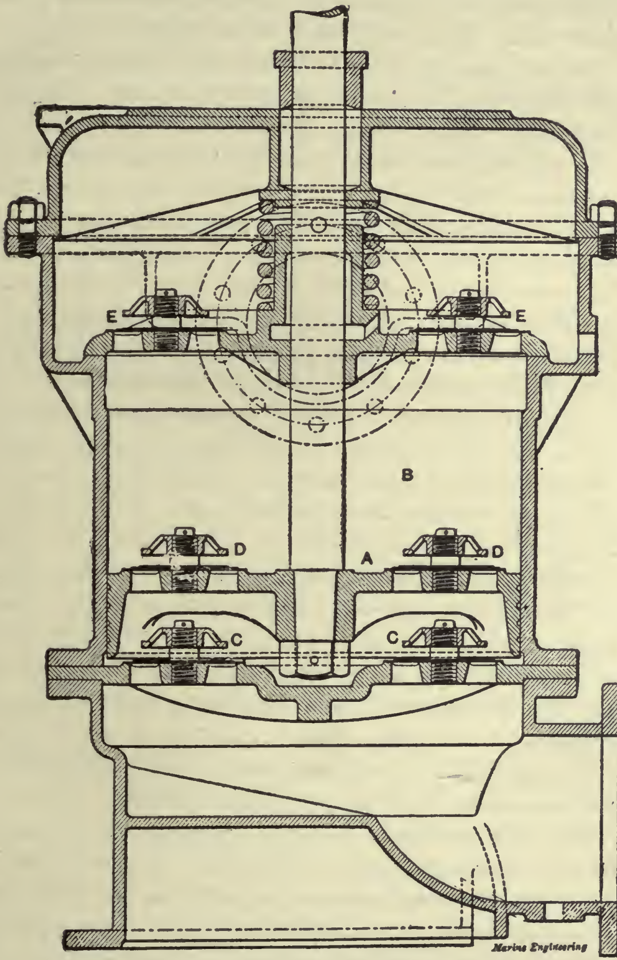

FIG. 23.—VERTICAL ATTACHED AIR PUMP

made of cast iron, fitted with a thin composition liner. The bucket should be of composition, and the top and bottom valve plates should also be made of the same material.

"The air pump valves nowadays are usually made of several light bronze disks of decreasing diameters, the largest diameter being at the bottom. These are held down by light bronze wire spiral springs. Some engineers, however, still prefer vulcanized rubber valves.

"You will notice that the bucket shown in this sketch has a number of grooves turned in its rim; these are supposed to trap small quantities of water and thus prevent leakage from one side to the other. Ordinarily buckets of this kind are fitted with bull rings and packed with square hemp packing, as that is much more reliable than the so-called water packing.

"Pumps above 18 or 20 inches in diameter are usually fitted with a manhole in the side of the barrel, so as to provide ready access to the bucket and foot valves without removing the top and the bucket as well whenever it is necessary to examine the lower sets of valves.

"What pump on board of a ship do you think has the easiest job?" inquired McAndrew, trying to test the knowledge of his pupils.

"I know," quickly said O'Rourke, "it's the pump in the firemen's washroom when Schmidt is taking a bath—he's afraid of water."

"I haven't heard of any pump handles being broken when you were taking a bath, either," retorted Schmidt.

"Well, you will have to decide the bathing proposition yourselves," remarked McAndrew. "But what I wanted to call to your attention is the fact that the circulating pump, a very important adjunct of marine machinery, has comparatively little hard work to do. In condensing the exhaust steam a very large quantity of circulating water is used, as for every pound of steam condensed there is required under ordinary

conditions the cooling effect of about 30 pounds of sea water. Thus for a 4,000-horsepower engine, using about 16 pounds of steam per horsepower each hour, there would be required about 3,800 gallons of circulating water per minute. This water has, however, only to be pumped with sufficient force to overcome the friction through the tubes and the small head due to forcing it overboard a few feet above the pump. The requisite force is so small that on fast torpedo boats there is a scoop arrangement at the in-take which, when the vessel is going at full speed, is sufficient to drive the circulating water through the condenser without the help of the pump.

"The pump almost universally used for circulating purposes is of what is known as the centrifugal type—with the accent on 'trif' and not on the 'fug,' as I have heard some of you boys pronounce it. By the way, does any of you know the meaning of 'centrifugal?'"

Not even O'Rourke ventured a reply, so McAndrew informed his hearers that "'centrifugal' means 'flying from the center,' the opposite effect, or 'flying towards the center,' being expressed by the word 'centripetal.' A pump of the centrifugal type is therefore one in which the water entering at the center is driven outward by a revolving series of blades called the 'runner,' and is discharged through an opening in the casing which is connected by a pipe to the condenser. This is an ideal type of pump for circulating the water through the condenser, inasmuch as a large quantity of water can readily be handled at a small expenditure of power. Pumps of this description are ordinarily operated by a single-cylinder engine of the usual type. An extension of the crankshaft of the engine forms the shafting for the pump runner, and inside the pump casing this shafting is usually encased in composition. The runner is generally cast of composition, but with the exception of small pumps the pump casing is made of cast iron, in halves, flanged and bolted together. Pumps of this de-

scription need but little attention, as there are no valves to get out of order as is the case with the ordinary types of reciprocating pumps. Being of such an advantageous type, centrifugal feed pumps are now used on shipboard to a limited extent, little difficulty being encountered in forcing water into a boiler against a pressure of as high as 200 pounds. Feed pumps of this description are driven by small steam turbines."

"Suppose the circulating pump should break down, how would you keep running?" inquired the observing Nelson.

"There is very little possibility of such an accident occurring, but it is a wise thing to prepare for even so remote an emergency," answered McAndrew. "I have seen some ships fitted with a special discharge pipe from the fire pump or the auxiliary feed pump to the water end of the condenser. I know of one ship in particular where the casing of the circulating pump collapsed on account of excessive corrosion on the inside. The chief engineer was a resourceful fellow, and fitted two hose connections to the small handhole plates on the water chest of the condenser; then by connecting up two lengths of fire hose to the fire main and running the auxiliary feed pump, he managed to keep sufficient vacuum in the condenser to run the engine along at half speed, and the ship got safely into port."

"Suppose your air pump busted, what would you do?" asked O'Rourke, not to be outdone in asking questions by his mates.

"Even the permanent disabling of the air pump need not put the engine out of business," replied the Chief. "If worse came to worse, you could take down the main exhaust pipe, rig up a temporary pipe out of heavy canvas, and exhaust to the atmosphere—tugboat fashion. Many steamers have a suction pipe connecting the channel-way under the air pump direct to the main feed pump. By this method the condenser can be kept clear of water, and a fair amount of vacuum maintained.

"You will find, as you live longer, that the application of good common sense and some ingenuity will help you out of many difficulties which at first seem insurmountable. These attributes are possessed by almost every marine engineer, as the very nature of his business requires a liberal use of both of them. Those are the qualities which make marine engineers the best operating engineers for any type of machinery."

CHAPTER XIII

Feed Water Filters, Pumps and Injectors

"Having followed the steam along until it is condensed into water, our next step will be to get it back into the boiler, ready for its transformation into steam again; incidentally we will stop at one or two of the way-stations, as they say on railroads.

"After the water leaves the hot well or the air pump, it is usual to subject it to a filtering process in order to remove the grease and other impurities which become mixed with the steam as it passes through the engine. Impure water is just as bad for boilers as it is for human beings: while an occasional dose of oil is said to be good for the human system, it is never good for a boiler's 'system,' hence every effort is exerted to keep it out of the feed water. Most ships are fitted with what is known as a filter tank, which serves the double purpose of a reservoir for the feed water and a receptacle for filtering materials.

"The filter tank is customarily fitted with a number of compartments through which the feed water is drawn by the action of the feed pump—usually going up in one compartment and down in the adjoining space. By this means for a distance of from four to ten feet, according to the size of the tank, it flows through the filtering material, and the oil is supposed to be caught thereby. The material most commonly used is 'excelsior' (small wooden strings), because of its fairly good qualities for absorbing or entrapping the grease globules as well as its very cheap cost. Ordinary hay is some-

times used, but it is not as efficient as the excelsior. Sponges are used to some extent, but they are so expensive that they cannot be thrown away after becoming oil-soaked, and cleaning them to be used again is not a job relished by the oilers and firemen. A spongy vegetable substance known as 'loofa' is occasionally used, but that too is expensive and has to be washed out and replaced in the compartments. There are several patented filters on the market which utilize various woven filtering materials, such as gunny sacks, etc., but they are all for the accomplishment of one object—the removal of grease and oil, the only real, thorough cure for which is to refrain from its use entirely."

"That," interrupted O'Rourke, "is like curing a mad dog by cutting off his tail close up behind his ears."

"You have the idea all right, but you will find that both these remedies are difficult of accomplishment," answered the instructor.

"Now as to the feed tank's use as a reservoir—it should have an ample capacity for at least five minutes' supply of feed water for the boilers when the engine is running at full speed, in order to allow for the fluctuations between supply and demand in all steam plants. When feed pumps were located in the fire rooms, water tenders would have to run back and forth to see that the water in the tank was not so low that the feed pump was pumping air into the boilers, or else not so high as to be overflowing into the bilges. The proper system is to have the feed pumps located in the engine room as near as practicable to the feed tank, then by means of a float, rising and falling with the level of the water, and connected by means of rods and bell cranks to a micrometer valve in the main feed pump steam line, the system is so regulated that the water level in the tank can be automatically adjusted.

"We are now up to the subject of boiler feeding, and in this

connection I will ask you: How does your supper to-night compare in importance with feeding the boilers?"

"We get our feed and some money besides, while as far as I can see all a boiler gets is its feed," said Pierce.

"No, that isn't it," broke in O'Rourke, "a boiler lives on liquid food and has to be fed all the time it is working, while we have to work all day and only get fed once in a while—and it's pretty bum stuff at that. Mr. Boiler, though, has to have his feed of the purest brand."

"That's true," replied McAndrew, "but you must remember that the boiler's stomach is only of steel, while from what I hear, you have a copper-lined stomach.

"However, I am glad that you appreciate the fact that a boiler has to be fed continually while it is working, as that is the most important thing an engineer has to contend with. If anything goes wrong with the main feed pump there is the dickens to pay, as the boiler's appetite for water allows of no delay.

"On most ships there are at least three means of forcing in the feed water—the main feed pump, the auxiliary feed pump and the injector. It would be a rare series of accidents, indeed, when at least one of these contrivances would not be available for feeding purposes.

"The most important is, of course, the main feed pump, as that has to do the brunt of the work. It is customary to make this pump of the duplex type—that is, having two steam cylinders and two water cylinders, so arranged that the valve gear of each steam cylinder is worked from the crosshead of the other pump. Some engineers prefer the simplex type, and, in my opinion, there is really very little choice, except that the simplex type costs less and occupies comparatively less space. The choice between horizontal and vertical pumps is also largely a matter of opinion, as there are engineers of equal standing who have preference for both types. The best

feed pump is the one that gives the least trouble and is the most reliable, no matter whether it is simplex, duplex, horizontal or vertical."

"Which one is it?" inquired Schmidt.

"That's something you will have to learn for yourself, from your own practical experience," answered McAndrew. "I have heard good engineers argue themselves black in the face as to the relative merits of different types of pumps, and at the end neither convinced the other that he was right.

"Everybody will, however, agree that a main feed pump should be made as simple and strong as possible; that its water cylinders should be made of solid composition if you can afford it; that its steam valve gear can be readily adjusted, and that it keeps running constantly without much watching."

"How is it," inquired Nelson, "that a pump using steam of boiler pressure can force water into the boiler against the same pressure?"

"That is very simple," replied McAndrew, "as a boiler feed pump is somewhat on the principle of a lever—that is, the steam cylinders are always larger than the water cylinders. For example, a common proportion for an ordinary feed pump is to have steam pistons 8 inches in diameter driving water pistons or plungers 5 inches in diameter. Nelson, what would be the leverage in a pump proportioned like that?"

"Why, let me see," replied Nelson. "Oh! Yes, it would be 1 3/5 times as much pressure on the steam piston as it is against the water piston."

"Oh, no!" smilingly said the instructor, "you are wrong—we are not dealing with straight lines in this case; if it were a bar lever we were using to force the water into the boiler your answer would be correct, but cylinders have circular pistons, so the proportion between them varies with the squares of the diameters."

"What's that mean, sir?" said Nelson.

"By the square of any number is meant the product obtained by multiplying the number by itself. Thus the square of 5 is 25 and the square of 8 is 8 times 8, or 64; hence the leverage we gain in this particular pump is equal to 64 divided by 25, or 2.56. In other words, there is a load on the steam piston of 2.56 times that necessary for the water piston to exert a force equal to the boiler pressure. This proportion is found to be ample to insure the water being forced into the boiler against the boiler pressure, friction in the feed pipes, check valve, etc. Always remember the rule I have given you about comparing things having circular sections and you won't fall into the error I once saw a man make of fitting two 2-inch drains to carry off the water put into a tank by one 4-inch supply pipe. Tell me quickly, O'Rourke, how many 2-inch drains should he have fitted?"

"Four, of course," replied the Hibernian.

"Fine work!" said McAndrew.

"A good guess," sneered Schmidt.

"There is usually only one suction pipe and one discharge pipe to the main feed pump, so that it will draw water from the feed tank and discharge into the main feed line only. There can then be no complication and no danger from opening the wrong valves when the pump is first started up. A properly proportioned pump should work easily and quietly.

"The auxiliary feed pump is, as you probably know, used in case the main feed pump breaks down. Many people call this the 'donkey pump,' just for what reason I do not know."

"I know why that old pump on this ship is called a 'donkey' —it's because it bucks and kicks so much," suggested O'Rourke.

"It must do that when you are running it, then," retorted McAndrew. "I never saw it act that way. It's all in knowing how to run a pump—you probably tried to start it without

opening any of the discharge valves. I think the 'donkey' must have been on the other end.

"The 'donkey pump' is, of course, used for many other purposes than as a boiler feeder. It generally has four or five suctions and as many discharges. It can be used for pumping out the bilges, pumping out the boilers, for fire purposes and for washing down decks. When you use this pump you must be very careful to see that you open the right valves. I remember catching one oiler who was on this ship pumping bilge water into one of the boilers simply because he had opened the wrong suction valve. I fired him at once, as there is no place on this or any other steamship for such careless people.

"The auxiliary or 'donkey' pump is frequently a duplicate in construction of the main feed pump, but if possible the water end should be of composition on account of handling salt water. On all well-designed feed pumps there is an air chamber, both on the suction and discharge sides. These answer the purpose of a cushion for taking up the shock. Water is practically non-compressible, so that a sudden stroke of the pump acts like a hammer on the whole pipe system unless there is an air chamber wherein the air is compressed like a spring. No work is lost, but the shock of impact is prevented.

"There is another method of feeding water into a steam boiler besides the main and auxiliary feed pumps, and it is of such importance that every ship should be fitted with at least one. This is known as the 'injector'—an apparatus which occupies very little space but is highly efficient and often very useful. Fig. 24 is a sketch of an ordinary type.

"In the figure shown, the steam is admitted through the pipe *B*, the entrance to the body of the injector being controlled by the valve which is operated by the handle *K*. When this valve is opened, the steam rushes through the contracting nozzle *S*. The air in the space around the two openings shown is mixed with the steam and forms a partial vacuum sufficient

to draw in the water through the pipe *B*. This water combines with the steam and passes into the combining and delivery tube *C D*. The steam is condensed in this tube by contact with the water, and the jet thus formed is given a very high velocity, ample to lift the check valve and force it into the boiler. It is really the energy of the inrushing steam which gives the water sufficient momentum to carry it into

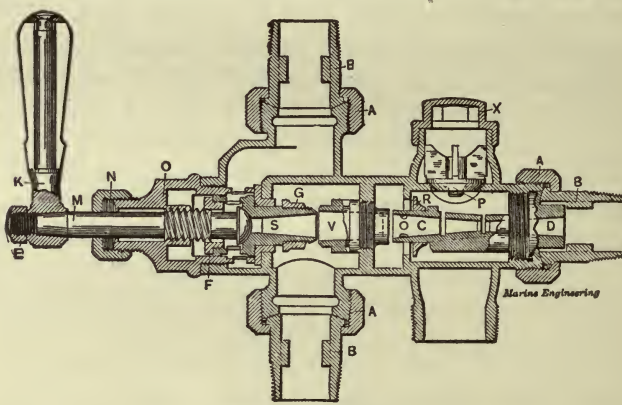

FIG. 24.—INJECTOR.

the boiler. The great advantage of such a device is that it acts as a feed water heater, the water going into the boiler being heated by the steam which gave it the momentum.

"For some reason or another, people who locate injectors never seem to get them piped up right. They should be arranged so that the lift of the water will be very small—not over 4 or 5 feet at the greatest—and the discharge pipe to the boiler should be as direct as possible so as to avoid any sharp bends. You have all heard the expression that 'four round turns are equal to a blank flange.' That is not exactly so, but it is nevertheless true that every round turn or right-angled bend in a pipe greatly increases the friction of the water passing through it.

"In recent years engineers generally recognize the great advantage of a feed water heater, so that no new vessel is turned out without one of these aids to economy. Ten or fifteen years ago it was not generally the practice to fit a device for warming the feed water, but now one of the greatest problems which confront all marine engineers is to get the greatest amount of work out of the least amount of coal. No single apparatus connected with marine machinery has done more to produce economy of fuel consumption than the feed water heater, a device primarily to utilize heat which has heretofore been wasted through the discharge water from the condenser. Many devices have been invented to heat the feed water by means of the waste gases from the furnaces, but the liability of accidents to the piping thus employed has practically put them out of use. Hence, nowadays, it is almost the invariable practice on steam vessels to have the feed water heated by means of a portion of the exhaust steam from the auxiliaries, such as the dynamos, feed pumps, air pump (when independent), etc. The best form of feed water heater of this class is where the steam does not come in contact with the feed water. In other words, the modern feed water heater is practically a small surface condenser where the feed water is the circulating medium. These are of various types, some having straight tubes with tube sheets like an ordinary condenser, and others having spiral coils connected to manifolds at the ends. Heat from the exhaust steam is thus transmitted to the feed water, so that it is possible to have the feed water enter the boilers at as high a temperature as 240 or 250 degrees Fahrenheit."

"I thought water boiled at 212 degrees," suggested one of the class.

"So it does," said McAndrew, "under atmospheric pressure only, but I have previously pointed out to you that the boiling point of water varies with the pressure, and in this case the

pressure of the feed water is higher even than that of the steam in the boiler."

"Where does all the saving come in?" inquired Nelson.

"I'll show you," said the instructor, "as it is quite simple. We will suppose that we are using steam at a boiler pressure of 180 pounds per square inch, and that the feed water we have been using is only 100 degrees, rather cold, but still it is such as is sometimes used when great care is not exercised by regulating the circulating pump. Now suppose we have yielded to common sense and fitted the vessel with a feed water heater of the exhaust steam variety, and we find by the thermometer in the feed pipe that the water is entering the boiler at an actual temperature of 230 degrees Fahrenheit. We have thus caused a gain of 130 degrees Fahrenheit. From the 'Steam Tables' we find that steam at 180 pounds pressure contains 1,198 B. t. u. By a simple calculation we then find how much is saved, thus:

Total heat in 1 pound of steam....................	1,198
Heat in feed water as used originally (100 — 32)...	68
Heat required to form 1 pound of steam under old conditions	1,130

Under the new conditions we have saved 230 — 100 = 130 B. t. u.'s, and we find that we now only have to use 1,130 — 130 or 1,000 B. t. u.'s for a pound of steam. To find the ratio of saving we divide 130 by 1,130 and it gives 11.5 percent. Thus, if the ship has been using 100 tons of coal for a certain run between ports, it will be found after the feed water heater is fitted that 88.5 tons will do the same work. At $3 (12s. 6d.) per ton there will be a saving each trip amounting to $34.50 (£7 3s. 9d.). For 100 trips a year the saving in coal would be $3,450 (£707), or more than enough to pay for the new heater the first year it is used.

"The saving in fuel is not the only benefit to be derived, as the use of hot feed water undoubtedly prolongs the life of the boiler and prevents many leaks in the seams which result from the use of cold feed water. We might compare the bad effects of the use of cold feed water in boilers to the bad effect on a man's health of drinking too much ice water."

"Would it make his seams leak?" asked O'Rourke.

"No. But it often makes his stomach ache, and he will not last as long as the man who slakes his thirst with water only moderately cold.

"We have now followed the feed water through its various manipulations, and it is prepared to enter the boiler, except for one important essential, and that is taking the air out of it. Many of the ills which befall the interior surfaces of boilers are due to the air which enters with the feed water. There is not in general use any simple device to accomplish this, however, as designing engineers, as a rule, do not pay much attention to this important matter. If a pet-cock is fitted at some bend in the pipe, or if some obstruction is fitted in the pipe, considerable of this air can be blown off, and there are also certain automatic devices which can be used for blowing out the entrapped air. In watertube boilers where the feed water enters above the surface of the boiler water in the steam drum, the air is released to a considerable extent by having the feed water discharge against a small hood over the feed pipe nozzle, so that it enters the boiler in a spray, the air becoming separated and being carried off with the steam. There can be little corrosion in boilers without the oxygen in the air, so that the exclusion of air from the water tends greatly to reduce the pitting and corrosion.

"The feed pipes leading from the feed water heater to the boilers are usually made of seamless drawn brass or copper, and should run as nearly straight as possible to avoid friction. These pipes, as far as possible, should be run where they are

easily accessible in order to detect any leaks, and by all odds the joints should be located where they will be easily accessible for putting in new gaskets, as a leaky joint in a feed pipe is intolerable."

"What's that?" said O'Rourke.

"That means something that we cannot stand for, very much like some of your questions."

CHAPTER XIV

Evaporators and Distillers

"Which one of you knows the difference between an evaporator and a distiller?" said McAndrew, at the commencement of the evening's lecture. Before any of the rest of the class could reply, the ever-ready O'Rourke blurted out, "One of 'em makes dried apples and the other makes booze."

"You are always talking about something that is most familiar to you, O'Rourke," sarcastically replied the instructor; "while it is true that 'booze' is distilled, we are dealing with water exclusively just now.

"You may remember that when we had the subject of boilers under consideration, I told you that nowadays only fresh water is used in the boilers. The steam from the engine is condensed over and over again and pumped back into the boilers; but in spite of all the precautions the engineer can take, there is more or less of the water lost on account of leakages around the boilers, at the pipe joints, and around the stuffing-boxes of the main engines and the auxiliaries. Just how much this leakage amounts to, it is hard to estimate, but a goodly supply of fresh water should be carried in the ship's tanks to make up the deficiency of feed. When that is used up, as it generally is after five or six days' steaming on most vessels, then we have to have other means for furnishing the fresh water. Of course, there is always as much salt water to be had as you may want, but the problem is to extract the solid matter from the sea water so that it will not be deposited on the heating surfaces of the boilers. For this pur-

pose the evaporator is used, and you may as well understand that an evaporator is simply a boiler which uses steam to generate steam from sea water. The donkey boiler or one of the main boilers could be used for evaporating purposes but for the fact that the scale would be deposited on their heating surfaces, which are difficult to clean. Hence the most successful evaporator is the one that is easiest to clean. By using steam from the main boilers to generate steam in the evaporator, no fresh water is wasted, as the steam from the inside of the coils is condensed and passed back into the feed tank or condenser.

"The coils or tubes of an evaporator are usually arranged so that they can be pulled out or gotten at quite readily for cleaning purposes, for after only a day's use they are usually quite heavily incrusted with scale. Scaling evaporator coils at sea is a delightful job, and I am sure that you, O'Rourke, will be tickled to death to do your share of it."

"Huh!" said that worthy, "I have already done one trick at that business the last ship I was on. I worked so hard at it that I punched a hole through one of the coils, and the first assistant told me I was too strong for such scientific work."

"The chances are you did it on purpose to get out of work," said McAndrew, "but that shows you that care must be taken in scaling evaporator coils, as they are usually made of brass or copper, and, naturally, are as thin as they can well be made in order to better transmit the heat. The shell of the evaporator is made of steel, about the same as you would build a small boiler, only it is a good idea to add at least one-eighth of an inch to the thickness of the plate in order to allow for the excessive corrosion which always takes place around the water-line.

"There is quite a knack in running an evaporator, as you will find from experience. The principal thing to guard against is excessive foaming. If the water is carried too high in the

glass, it will boil up and, mixing with the steam, will be carried over with it. For some reason the water in an evaporator foams more than it does in a boiler of the same size, hence its height must be watched carefully, and all evaporators should be fitted with baffle plates and dry pipes. If the detilled water is being run into a tank for the use of the ship, a little carelessness in allowing the salt water to lift might result in spoiling a whole lot of good drinking water.

"After the steam is generated in the evaporator, it is usually passed into the main condenser, where it is condensed into water along with the exhaust steam from the engine, and thus makes up the deficiency in the feed water."

"Where does this distilling business come in?" inquired Nelson.

"Oh, yes," replied McAndrew, "I almost forgot to tell you that on shipboard, as well as on shore, the distiller is used for drinking purposes, only that the ship's product is exclusively pure water. A ship's distiller is in reality only a small condenser, and is usually made of copper or brass; the sea water is used for cooling purposes, and, passing on the outside of a number of small brass or Muntz metal tubes, which have been carefully tinned, condenses the steam from the evaporator into fresh water, which is run into tanks and used for drinking or culinary purposes."

"I know all about the drinking end of it, but what's this 'culinary' stunt?" inquired O'Rourke.

"If you ever hung around the galley any, you must have noticed that the cook uses considerable fresh water to make coffee, soup, etc," replied McAndrew; "that's 'culinary'—perhaps I should have said 'cooking' purposes."

"Oh! I see," said O'Rourke; "the difference between 'culinary' and 'cooking' is about the same as the difference between a 'cook' and a 'chef.'"

"To return to the subject. I forgot to tell you that the feed

water for the evaporator should not be taken from the sea direct, as it has to be heated up to the boiling temperature, so it is customary to take it from the discharge water from the main condenser, which has already been heated up to between 120 and 140 degrees; there is thus a considerable saving of heat units by using the discharge water instead of the cold sea water.

"Some ships have several evaporators in series, the steam in the first one being raised to 60 or 80 pounds pressure and then passed along to the next evaporator, where it is used to generate steam; the steam in the second evaporator is carried at a pressure of from 10 to 15 pounds, and this, in turn, is used to generate steam in a third evaporator, wherein the steam is sometimes at a pressure below that of the atmosphere, but it readily flows into the main condenser, where the vacuum is less. Such an apparatus is known as a triple-effect evaporator, and there is a considerable saving by such means. However, the first cost is so great that it is but seldom used.

"I must also tell you of a good wrinkle in scaling an evaporator where the coils are of the spiral type. A sudden change of temperature will tend to crack the scale, so that by a slight tapping with a wooden mallet it will drop off readily. To obtain this sudden change of temperature, the evaporator should be emptied of all water and steam turned on the coils until they are as hot as it is possible to get them. Then start your evaporator feed pump up as fast as it will run, open the bottom blow to the evaporator, and the valve connecting the evaporator to the main condenser, if there is a vacuum in it. The cold sea water will then rush in at such a rate as to give the sudden change in temperature desired. This effect can also be brought about by heating up the coils, taking off the lower manhole plate of the evaporator, if such is provided, and then turning the fire hose on the coils."

CHAPTER XV

Electricity

"One of the most important of the auxiliaries on board a modern steamer is the dynamo for generating electric current for lighting and ventilation purposes. The study of electricity presents a very large subject in itself, but it is essential that all marine engineers have at least a fair insight into the general principles involved. I will therefore give you a few hints on the subject which will, I hope, be of interest and benefit to you.

"In commencing my remarks on the subject, I will ask if any of you know what electricity is?"

A silence followed this question, which was finally broken by O'Rourke, who said, "I did know once, but I have clean forgotten it."

"Too bad! Too bad, entirely," said McAndrew; "what a loss to the scientific world! To think that you once knew the mystic key to this great question which no living man has ever solved, and that you have forgotten it! You certainly should be punished for such monumental carelessness in keeping from the public the true answer to this hitherto unanswered problem. Well, we will have to continue in our ignorance, and although no one but O'Rourke has ever really known what electricity is, we, in common with all others, will have to devote our attention to studying its effects.

"The name 'electricity' comes from the Greek word 'electron,' meaning amber, as it was from rubbing this material with a catskin that the phenomenon was first noticed. There are three principal ways of generating this current, as it is

generally termed. The first might be termed 'frictional electricity,' as it is generated by rubbing such substances as glass and silk together; you may also have noticed its effect by scuffiing your feet on a woolen carpet and then touching some metal, such a a gas jet or brass bed, when you can generally see, hear and feel a slight electric shock. This method of generating electricity is not, however, used practically.

"The second method might be termed 'chemical electricity,' from the fact that a current is set up by immersing two different metals in a chemical solution. Copper and zinc are most commonly used, as it is found, when these metals are immersed in a mild solution of sulphuric acid, a pronounced flow of electrcity is set up between them. This combination is known as a cell.

"A number of cells form a battery, and electricity from such a source is largely used for operating telegraph lines, alarm bells, etc. What are known as 'dry batteries,' wherein electrcity is formed by the chemical decomposition of zinc in the presence of carbon surrounded by a paste made of plaster, flour or chemicals, are particularly useful on shipboard, as there is no liquid to be spilled by the rolling of the ship.

"The third method of generation might be termed the 'magnetic system.' You all know of and have played with the ordinary toy horseshoe magnet. The two ends of a magnet are known as 'poles,' and you no doubt have observed that there is an unseen force acting between these poles, sufficiently strong to attract or pick up small pieces of metal, and that it is particularly strong in picking up iron or steel. This ability of attracting pieces of metal is attributed to what are known as 'lines of magnetic force' which exist in the magnet. Some of the early experimenters discovered that if certain combinations of wires were revolved between these poles of a magnet —or the 'magnetic field,' as it is called—a current of electricity would be set up. Proceeding on this principle, the modern

dynamo has been evolved. I will not attempt to mystify you by going into the theory of how this is done, as I feel quite sure that after I had finished you would probably have a hazier idea than you had before, so I will confine my remarks to some of the practical things which you should learn about the subject.

"This 'magnetic system' of producing electricity is used almost exclusively for all lighting and power purposes. The modern dynamo for producing current is to all intents and purposes a large magnet, and the bunches of wires revolving between its poles, and hence cutting the 'lines of force,' is known as the 'armature.' The current is collected by what are known as 'brushes,' generally blocks of carbon, held against the revolving metal.

"I do not expect you to grasp the idea of electricity immediately, as very few people do, but it will probably help you somewhat to compare it with water in a pipe system. In such a comparison we will consider the dynamo as a pump forcing water through a continuous line of pipe of varying diameter, according to the flow desired. We will suppose that the main leading away from the force pump is divided up into several branches, and that from each of these branches there are numbers of small spigots from which the water is being drawn. We all know that no water will flow from the outlets unless a pressure is put on by the pump. We also know that this water is being used at the various outlets, and that we can determine how many gallons per minute is being used if we so desire. You can also readily understand that the water will not flow through the pipe line as readily as it would if simply pumped overboard directly from the discharge valve, on account of the friction of the water as it slides or flows over the inner surfaces of the pipes. Now we must imagine that electricity is being used instead of water. The wires, proportioned according to the amount of flow required, take the places of

the pipe and its branches. The electric lights, distributed along the branches, take the places of the spigots in the pipe line."

"The pressure of the water corresponds to what is known as 'electro-motive force' for electric currents, and the unit is known as the 'volt.' Thus we have on the switchboard of all electric plants a 'voltmeter,' which corresponds to the pressure gage in a pipe line; in other words, we read the electric pressure from the voltmeter, and it is well to note that the standard pressure for lighting currents on shipboard is 110 volts.

"The resistance to the flow of water through pipes corresponds to the resistance of the flow of electricity through wires, and the unit of this resistance is called an 'ohm.'

"The rate with which water flows through a pipe in a given time is expressed in so many gallons per minute; in electricity the rate of flow is expressed in a unit known as an 'ampere,' which means the amount of current produced by a pressure of one volt acting against a resistance of one ohm.

"Electric power, like mechanical power, must take into consideration the element of time, and the unit of this kind of power is known as the 'watt,' which is the power produced by a current of one ampere at a pressure of one volt for one second."

"Where do they get all these funny names like volt, ampere and ohm?" inquired Pierce.

"They are derived from the names of the early scientists who studied this subject, and in this way their fame will be handed down to future generations. Volt comes from the Italian named Volta, who was an early experimenter in the subject. Ampere was another early scientist, and you ought to know that Watt was the inventor of the steam engine. If you had been around in those days, and made the experiments, the unit of pressure might have been a 'pierce' instead of a 'volt.'"

"I'll bet," said Smith, "that the unit of resistance or friction

would have been an 'O'Rourke' if he had been around in those days."

"One thing sure," replied McAndrew, "the unit of work—'ampere'—would never have been displaced by anything that sounded like an 'O'Rourke.'

"The 'watt' is a much smaller unit than the horsepower, and, in fact, it takes, theoretically, 746 watts to equal one horsepower. That doesn't mean that a one-horsepower engine would produce that many watts, as there are too many losses between the two, but it is known as the theoretical equivalent. In speaking of the rated power of a dynamo or generator, the general term is 20 K.W., 50 K.W., etc., as the case may be. The K. means kilo, the Greek word for one thousand, so that a 20 K.W. machine means one that is capable of producing 20,000 watts.

"To utilize electricity for lighting purposes, it was necessary to invent an electric lamp, and this fell to the lot of Edison, an American inventor, who, after many months of experimenting, found that a filament of carbonized bamboo, placed inside a glass bulb from which all the air had been exhausted, would heat up to an incandesence when an electric current was passed through it. If the air is not exhausted from the bulb, the oxygen in the air would cause combustion, which would burn up the filament almost instantly. Many metallic substances are now used for filaments, and are known as 'tungsten,' 'mazda,' 'tantalum,' etc. These are much more efficient than the old-style carbon-filament lamps, that is, they give much more light for the same amount of current used. The ordinary carbon-filament 16-candlepower lamp is generally used on shipboard; this lamp requires about ½ ampere of current or 55 watts. If we know the voltage of a current and the amperage, how do we tell how many watts will be used?" asked McAndrew of the class.

"Wait until you get the bill from the electric lighting company," suggested O'Rourke.

"You can't be too sure of that," replied the instructor, "as most people have an idea that gas bills and electric light bills are not made out on a strictly scientific basis. The right way to ascertain that fact is to remember that the watts are equivalent to the volts multiplied by the amperes. In this case we have 110 x ½, which equals 55. If we were using 20 amperes of current at a pressure of 10 volts the result would be 20 x 10, or 200 watts.

"An ordinary 16-candlepower lamp, using 55 watts of current, will require, on an average, 1-10 horsepower at the generating engine, so I want to impress upon you the importance of turning off electric lamps which are not needed in any part of the ship, as they soon eat into the coal pile to a considerable extent, for every hour that a 16-candlepower lamp is burned there is nearly a pound of coal used under the boilers.

"I want to call your attention to the instruments used on the switchboard, which is the name of the apparatus by means of which the current is distributed. The whole electric light system is divided up into circuits or branches, corresponding to the different parts of the ship. For example, there is usually a complete circuit for the engine room, one for the fire room, one for the social hall, etc. If these were water-pipe connections there would be a valve in the pipes at both ends of the circuit. For electricity, what is known as a switch or cut-out is used, and generally located on the switchboard. They are usually of the double pole type, that is, they cut out both the sending side and the return side simultaneously.

"Unlike water, electricity is liable to sudden fluctuations of both pressure and volume; unless some means of easement is provided, damage is liable to result to the wiring or fixtures. Hence at various points in the circuit the current is made to

pass through short lengths of some fusible alloy, which, when subjected to an unusual current, melts and breaks the circuit. These are made in two types, the link and cartridge; one is a plain wire, and the other is a wire encased in a fiber tube. The action in this case is similar in effect to the blowing off of a safety valve.

"The ammeter is an instrument for indicating by a needle on a dial the amount of current being used, which varies, of course, with the number of lights and fans in use.

"The voltmeter, or pressure gage, has the same function as a steam gage on the boiler.

"The rheostat is an instrument for using up surplus energy or current, and consists of a series of coiled wires which can be connected up in the circuit by moving a handle across the contact points. You probably know that when the main engine of a ship is required to run slowly, and the boilers temporarily making more steam than can be handled by the engine, it is customary to open what is known as the 'bleeder valve' from the main steam pipe, which allows the high-pressure steam to blow directly into the condenser. This is practically the same purpose for which the rheostat is used, the surplus current being dissipated by the increased resistance of the coils of wire which disposes of the electric energy in the form of heat.

"Now a word about wiring to transmit the current to the points where it is needed. As copper offers less resistance to the flow of electricity than any other metal of reasonable cost, it is used almost universally. In laying out the wiring for the ship, the sizes are determined to suit the quantity of electricity to be used in about the same manner that we would proportion piping for the distribution of steam or water. Small wires are made single, and for larger currents it is customary to use a number of small wires either parallel or laid up in the form of a cable. On shipboard it is of the first importance that the wires should be well insulated, that is, covered with a sub-

stance which prevents entirely, or to a large extent, any flow of electricity through it. The best and most used of such substances is ordinary rubber covered with braided silk or cotton to make the whole covering waterproof. Water is an excellent conductor of electricity, and hence any leakage through the covering on the wires will rapidly result in corrosion of the wires and leakage or short circuiting of the electric current. In the first marine electric installations the wires were run in wooden strips, but as it was difficult to keep them tight,

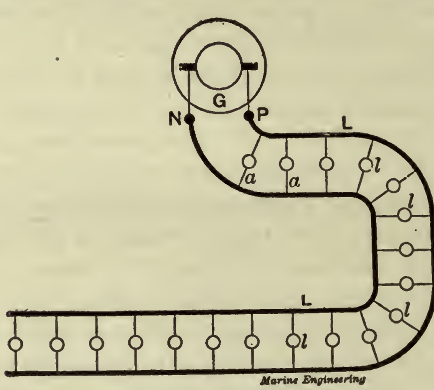

FIG. 24.—DISTRIBUTION IN PARALLEL

the almost universal practice now is to run electric wires in iron pipes known as conduits. Porcelain is another excellent non-conductor of electricity, hence we find that material used for various kinds of electric fittings and lamp sockets.

"The wires for electric lights on ships are usually run in what is known as 'parallel,' as shown in Fig. 24.

"Each lamp, you will notice, is tapped off between the two wires, so that each will draw a sufficient amount of electricity from the main to run the particular lamp.

"Other uses than for lighting on shipboard are fan motors and winch motors."

"What is a motor?" inquired one of the class.

"A motor," said McAndrew, "is simply a small dynamo running backwards. Electric fans are driven by means of the current passing through the wire wound around the magnetic poles, which causes the armature to revolve. The fan blades are secured to an extension of the armature. If the small armature was made to revolve by an engine or other source of power, the motor would generate electricity instead of using it up, and hence become a small dynamo.

"In closing my remarks on electricity, I want to impress upon you that, although it is not known definitely what it is, its effects are very well known, and there is no great mystery about it. You do not get something for nothing, as many beginners are apt to think. For all electrical energy generated and used, there is a still greater amount of mechanical energy exerted in its production. If the current comes from a battery, you have to produce it by the disintegration or wasting away of the zincs; if from a dynamo, it takes coal to produce it. The only free electricity we get is that from the clouds in the form of lightning, but no one has, as yet, found a method of utilizing currents from that source."

"What about Jersey lightning?" inquired O'Rourke.

"I suppose you refer to the New Jersey drink known as 'applejack,' and if that's the case, I haven't heard that that is free, either, but I understand its results are about as fatal as the lightning we get from the clouds. You probably know more about that than any of the others here."

CHAPTER XVI

Pipes and Valves

"The school will be in order," demanded McAndrew, as he entered "Highbrow Hall," it having been dubbed that by O'Rourke. The cause of this remark was a heated discussion which was being carried on by the four students as to whether the United States or Germany had the larger navy. Gus Schmidt and Nelson were maintaining that Germany was the more powerful, while Pierce and O'Rourke strenuously insisted that Uncle Sam was the superior on the water.

"Never mind about the navies of the world," said the instructor, "they're big enough to look after themselves—what you boys should be interested in is to be of some use to the merchant marine. I want to discuss this evening the subject of pipes and valves. We have dealt with boilers, engines, pumps, etc., and now we want to connect them up. This is, therefore, a very important matter, as much depends in the successful operation of marine machinery on having proper pipes to carry the steam and water and proper valves to control them. Piping on board ship can be divided into three general classes, *i. e.,* steam pipes, exhaust pipes and water pipes.

"The main steam pipe system is naturally of the greatest importance, as through this system the steam is passed from the boilers to the main engine.

"The material generally used for the main steam pipe is copper, on account of its great ductility, the ease with which it is worked and its freedom from corrosion. For sizes up to 10 and 12 inches in diameter it is made of seamless drawn

material in order to avoid the brazed seam, which is liable to be the cause of leakages. As copper expands or increases in length when heated up to the temperature of the steam it carries, great care is exercised by designers to make arrangements for this expansion to be taken up without damaging the pipe or its flanges. One method of accomplishing this is by means of the ordinary 'slip joint,' as shown in this sketch.

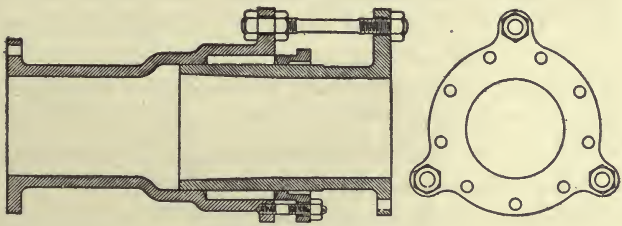

FIG. 25.—EXPANSION JOINT

"These, however, cause considerable work in order to have them properly packed, and have been known to pull apart and scald people who happened to be in the vicinity. The best method is to lay out the pipes so that there will be a number of large curves or bends in their length; the expansion then being taken up by the slight bending of the pipes. That is the reason you never see a large steam pipe run straight. As all pipes must be in such lengths as to get them in and out of the spaces they occupy for the purpose of making repairs, the sections must be securely bolted together. This, you may have noted, is accomplished by expanding the ends of the pipes into rings of cast iron or composition, called flanges, and after putting in some packing between the flanges, they are bolted up tightly together by means of a number of bolts of sizes to suit the diameter of the flanges. The making and keeping tight of these pipe joints is one of the most serious parts of an engineer's business. Various kinds of patented packings are used for making these so-called 'gaskets' for pipe joints; many

of them are excellent, some are good, and others are not worth two hoots. You will each have to learn from your own experience which is the best material to use, but be sure and get the kind which keeps the tightest joint and lasts the longest."

"Which one is that?" inquired Nelson.

"Ask each packing agent who tries to sell you some, and you will find that he has the goods," was the reply. "Some night when you are compelled to work an extra watch to replace a blown-out joint over the top of a hot boiler, just make a record of your thoughts regarding that particular kind of packing, and when you get back in port show it to the agent whom you patronized."

"Wouldn't we have to write those thoughts on some asbestos paper?" inquired O'Rourke.

"I think you would," said McAndrew.

"Main steam pipes on some vessels carrying very high-pressure steam are made of seamless drawn steel, on account of its strength being greater than that of copper. The disadvantages of steel for piping are the difficulty in making easy bends and its liability to corrosion. The flanges on steel pipes are sometimes made solid with the pipe, and this makes the strongest job obtainable for a joint of this kind.

"Auxiliary steam piping is made of copper, brass, iron or steel, according to the class of work. Seamless drawn copper is about the best that can be used, while ordinary wrought iron piping with screwed joints is often used in the cheaper kinds of work.

"Exhaust piping for steam is made of copper or iron, and it only differs from steam piping in being made thinner, as it does not have to withstand so high a pressure.

"Speaking of iron piping, O'Rourke, did you ever see a piece of ⅞-inch pipe?"

"Lots of it," replied the ever-ready.

"Well, I'm glad to hear it," said McAndrew, "you are prob-

ably the only one living who has ever seen that size; as a matter of fact pipe manufacturers do not make any ⅞-inch pipe or any ⅝-inch pipe, either. Just why they don't I am unable to say, but the old-timers who originated pipes for use around gas works probably had good reasons for not doing so.

"Just jot this down in your memories: Pipe sizes are ⅛ inch, ¼ inch, ⅜ inch, ½ inch, ¾ inch, 1 inch, 1¼ inches, 1½ inches, 2 inches, 2½ inches, 3 inches, 3½ inches, 4 inches, 4½ inches, 5 inches, and above that in even inches. If any one ever tells you to go and get them a piece of 1⅛-inch pipe, or any other size which is not in the list I have given you, they are trying to run you. Just tell them that the storekeeper is all out of that particular size.

"If any one ever asks you the diameter of a 1-inch pipe, don't think that it is a similar question to 'What times does the 12 o'clock train leave?' for it is not. While the 12 o'clock train may leave at 12 o'clock, a 1-inch pipe is always 1.05 inches inside diameter; a ½-inch pipe is .62-inch inside diameter, or nearly ⅝ inch. Here, again, the old-time gas engineers got in their work; but if you don't like standard sizes you can go without them; they have come to stay, and you might as well try to buy cheese by the yard instead of by the pound as to get manufacturers to change these old-established standards.

"For high pressures, pipes are made 'extra heavy' and 'double extra heavy,' but the outside diameters are the same, the excess metal being put on the inside.

"Brass pipes are made of iron-pipe size, and are frequently used in small-sized steam and exhaust pipes. Iron and brass pipes are not bent so easily as copper pipes, hence to change direction in a pipe lead, or to reduce or increase sizes, various standard fittings are used. These, naturally, are made of what is known as 'malleable iron'—a cast iron which is not as brittle as ordinary cast iron. Hence if the lead of the pipe is

to change at right angles, an 'elbow' is used; if one pipe is to branch off at right angles to another pipe, a 'tee' is used; if two pipes are to be joined together for permanent use, a 'coupling' is used; if sections of piping are to be put up so that they can be taken down, 'unions' are used, and let me say right here that for marine work you can't use too many 'unions,' as they're mighty handy fittings; then there are 'plugs,' 'caps,' 'reducers,' and various other devices for the convenient installation of piping, all of them made with standard pipe threads.

"For water piping on board ship, copper is almost always used for pipes which handle salt water, although in some cases for bilge pipes, lead is used. Copper has the advantage of not being corroded by salt water, and as it can be bent easily it makes an ideal material for such purposes. For the feed pipes, seamless drawn brass is frequently used for the straight parts and copper pipe for the bends. For the fire main seamless drawn brass is the best material, but as this is very expensive it is seldom used. A very good substitute material for use as fire mains is wrought iron or steel lined with lead. The iron or steel furnishes ample strength to resist the pressure, and the lead lining prevents corrosion of the interior, providing always that no leaks develop through the lining."

"What do you mean by 'seamless drawn?'" asked one of the class.

"When pipes were first made they were rolled up into cylindrical form out of sheet metal, and the seam brazed in the case of copper and riveted for iron or steel. A joint of either kind is an element of weakness, and leaks frequently start from imperfections in the welding or brazing of the joint. Of late years the art of drawing metal pipes from a solid block or ingot over a mandrel has taken great strides, so that to-day it is possible to buy either steel or copper pipes of any size up to 12 inches and over in diameter which have been drawn solid,

and consequently have no seams. Although at present the larger sizes of seamless pipe cost more than built-up pipes, the greater safety, due to the absence of joints, makes it advisable to use this pipe, especially for steam and water piping subjected to high pressures.

"In main feed pipes on board ship it is always necessary to make them in several lengths to facilitate their installation in crowded spaces, and to make them accessible for repairs. The location of flanges joining these sections together should be very carefully planned out in order to provide freedom of access in making new joints. When a leak occurs in a feed pipe joint it must be repaired very quickly, as boilers under steam won't run long without water. Every boiler is, of course, provided with both a main and an auxiliary feed connection, but no engineer ever feels very comfortable while even one of these pipe connections is out of order.

"Bilge pipes are sometimes made of lead, as I previously stated, but more often they are made of galvanized iron on account of the less cost. In connection with bilge piping it will be well to tell you something about the methods of getting water out of a ship's bilge, as every marine examiner will ask you something about that. The usual form of the question is, 'State how many means there are for getting water out of the bilges?' Perhaps you can answer it off-hand, O'Rourke."

"Sure," said that worthy. "Start the donkey pump, and if that doesn't do the trick put the firemen to work bailing it out with buckets."

"Starting the donkey pump would do for ordinary circumstances, but in an emergency, if you were put to work bailing out the bilges, I am afraid the ship would sink before you carried more than two or three bucketsful up the ladders; that is, if you didn't work any faster than you usually do.

"The usual method of pumping out bilges is by the independent bilge pump with which most ships are furnished.

This pump can be connected to all compartments of the ship through the manifold, from which pipes lead to all bilges. You may have noticed that valve near the circulating pump which is always kept closed, and should be locked or tied shut. In a great emergency, such as the ship grounding or in collision, the main circulating pump can be connected so as to pump out the bilges, by closing the main injection valves, and opening this emergency or bilge injection valve, as it is termed. On most ships the auxiliary, or donkey pump, usually is connected to the bilge manifold, so that it may also be put to pumping out the bilges.

"Many ships are provided with what is known as a 'bilge ejector,' whereby a jet of steam starts and maintains a syphon effect which forces the bilge water up and overboard. Such a contrivance is too wasteful of steam, and consequently of fresh water, to be used very freely on vessels plying the ocean. If all these devices fail to keep the water in check, then the best thing you can do is to pack your grip and take to the boats."

"How about saying your prayers?" inquired O'Rourke.

"I don't think that would work in your case," retorted McAndrew.

"A very important point in connection with pumping out bilges is to see that the strainers are cleared. The bilges of all ships, as you may know, usually contain ashes, chunks of waste, shavings and other refuse, and they have been known to contain a fireman's undershirt or overalls. These things if drawn into the bilge suction pipes would soon choke them up and the pumps would be useless. Hence it is that the end of every pipe is fitted with some form of a perforated strainer to catch the refuse before it can get into the pipes. The ordinary form is known as the box strainer, which, as its name indicates, is shaped like a box, and has all its sides and its bottom perforated with three-eighths or one-half inch holes. The top of the box is made easily removable so that it can be cleaned out.

Unless given attention frequently these strainers themselves become plugged up with dirt and refuse, and you young men will probably never appreciate the importance of keeping them cleaned out until you are called on some night while the ship is rolling and pitching in a gale of wind to dive down in bilge water up to your armpits for the purpose of digging bunches of waste and handfuls of ashes out of the strainer boxes. An old-time chief engineer in the navy conferred a lasting boon on seafaring men by inventing what is known as the 'Macomb strainer,' a device whereby the water is strained through a metal basket in a cast iron body with a removable top. By simply removing a clamp in the top of the strainer body the basket can be lifted out and emptied in two minutes. This invention has saved much profanity on shipboard, and probably many ships.

"In line with a talk on piping, and incidentally with profanity-provoking devices, we might stop casually and consider the steam trap, a necessary evil fitted to all steam plants. The primary purpose of a steam trap is to separate the water from steam in the numerous drains with which all marine machinery must be fitted. This is accomplished, or, I might add, is tried to be accomplished, in two principal ways: one by the automatic filling and emptying of buckets floating in the water of condensation, and the other by difference of expansion in metals as affected by the variance in the temperatures of steam and water. There are about as many different styles of steam traps as there are applicants for an easy job, but there are not more than two or three of these styles fit to use on board ship. I hesitate to tell you which they are, as I am a little uncertain even about their efficiency at all times.

"Of equal importance to the piping on board ship are the valves which control the flow of steam and water through them. Most of the work of the engineer, while the vessel is under way, is devoted to the opening, closing and regulating

of valves. Knowing how and when to perform these functions constitutes a large part of an engineer's practical knowledge. The efficient working of marine machinery is largely dependent upon the proper manipulation of valves, and on the other hand nine-tenths of all the trouble on board ship is occasioned by the wrong manipulation of these important details. With this

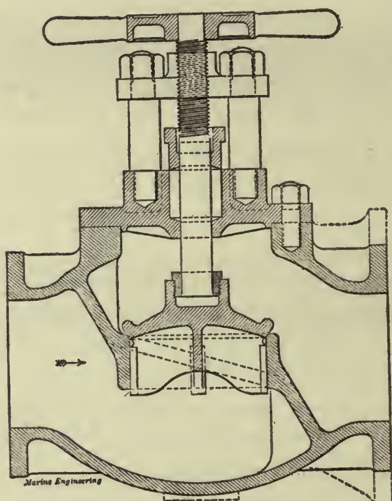

FIG. 26.—GLOBE VALVE

introduction to the subject you can readily see that it will be well to pay a little attention to them. The valves used on shipboard may be divided into principal classes—angle and globe, stop and check, and gate valves, and various combinations of these types.

"A globe valve may be defined as one in which the steam, water, etc., enters and leaves the valve flowing in the same direction; an angle valve is one in which the steam, water, etc., enters the valve flowing in one direction and leaves the valve

flowing in a direction usually at right angles to that in which it enters. Figs. 26 and 27 will illustrate these two types.

"A stop valve is one in which the disk is under absolute control of the hand wheel, and permits of flow through it in either direction.

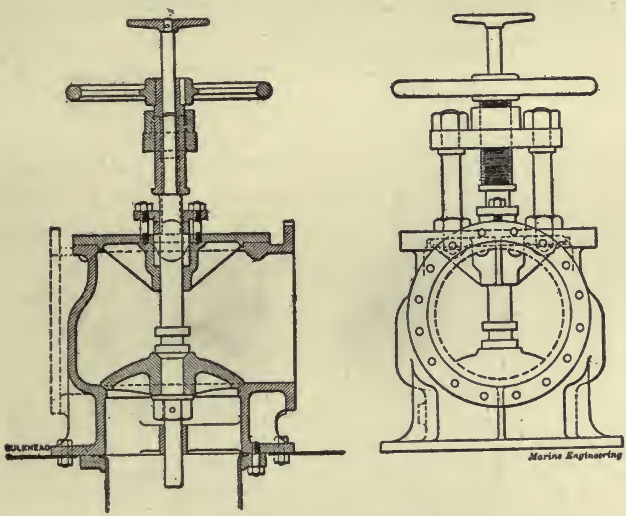

FIG. 27.—ANGLE STOP VALVE

"A check valve is one in which the stem is not connected with the disk, and permits of flow through it in only one direction. It can, however, be shut off by screwing down on the hand wheel.

"A gate valve is one in which the disk or gate is set at right angles to the direction of flow, and is at all times under control of the hand wheel. (See Fig. 28.)

"A cock is in reality a valve of the simplest design, wherein a conical plug is fitted in the body, and the flow of steam or water through it is regulated accordingly as the slit through

the plug is placed in line with the direction of the flow or at right angles to it.

"Valves of all descriptions are made principally of the best quality of cast iron, as that is the cheapest and best adapted metal for the purpose. Composition is frequently used for small valves and for larger valves in high-class work, on ac-

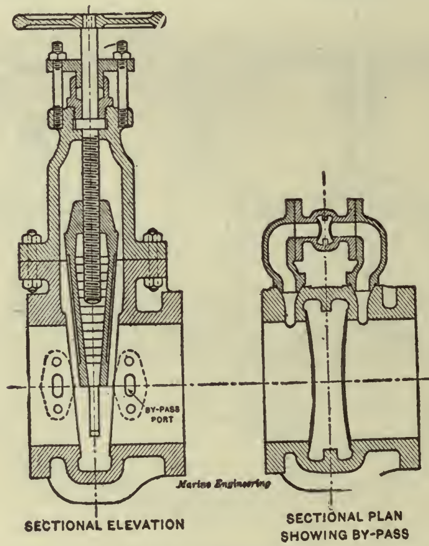

FIG. 28.—GATE VALVE

count of its freedom from corrosion and greater strength. Its increased cost, however, precludes its extensive use.

"Cast steel is used to some extent for valves subjected to very high steam pressures, owing to its great tensile strength, but the difficulty of obtaining good castings, free from blow-holes, limits its use to places where the greater strength is absolutely necessary.

"It is usual to have all cast iron valves 'brass mounted'; that is, to fit them with composition seats, disks, stems and

stuffing-boxes, as these are the parts subjected to the greatest wear.

"Seats of valves become grooved by the constant flow of steam or water, and if not attended to regularly are bound to leak. Therefore one of the frequent duties of an engineer is to 'grind in' leaky valves, an operation which consists of removing the valve covers, covering the seats with a ground-glass paste and revolving the disk in place until all grooves are removed. A valve reseating machine is a device for 'grinding in' valves mechanically while in place, the same as it would be done if the valve was removed and placed in a lathe. Such a device is a necessity in order to keep valves on a modern ship always tight."

"Chief, what is a reducing valve used for?" interrupted Pierce.

"Reducing valves are of comparatively recent use around steam plants, and have been made a necessity by the constantly increasing steam pressures now being used on board ship. While these high pressures are necessary for multiple-cylinder main engines to increase the economy of working, there are still certain auxiliaries on all ships which use lower steam pressures. Among these may be mentioned the ordinary reciprocating dynamo engines, the steering engine, the windlass engine, the bilge pumps, the heating apparatus, steam jackets, etc., and, in fact, wherever it is desirable to have low-pressure steam at a uniform pressure. These are devices whereby the high-pressure steam from the boilers may be reduced and delivered at almost any pressure desirable by regulating the reducer, after which, no matter how much the boiler pressure may fluctuate, a steady lower pressure is maintained for the auxiliaries."

"What is a relief valve, and why are they fitted on some pumps?" inquired Schmidt.

"A relief valve is simply a small safety valve," replied

McAndrew. "I have already told you why these are useful on the main engines. On some pumps, and especially fire pumps, it frequently happens that a careless oiler or machinist will start the pump full speed, and if there are not sufficient openings of the stop valves along the fire mains the pressure might rupture the pipe. For that reason one or more relief safety valves, set to blow off at a safe pressure, are fitted in the fire main, usually in the engine room, where the escaping water can do no particular harm.

"I have already explained to you that a valve need only be opened a vertical distance equal to one-fourth its diameter, and I hope you will bear that fact in mind. Remember, also, what I told you about not opening a steam valve quickly. That, however, does not apply to water valves, as they should be opened as quickly as possible.

"In closing this lecture I will call your attention to the pipe covering. In general all pipes transmitting either steam or hot water should be covered with non-conducting material, such as hair-felt for low pressures, and magnesia or asbestos, or the various components of each for the higher temperatures. Escaping heat not only lowers the efficiency of any steam engine, but it adds to the discomfiture of the men who have to operate the machinery. If you ever have to do any pipe covering remember that you should not cover any of the joints, as it is often necessary to get at them quickly to make new joints, or to set up on them when they leak. All pipe covering should be encased in canvas, and it should be sewed on instead of being pasted, as some contractors like to do.

"We have about covered in a general way all parts of a marine installation, and from now on I will direct your attention to what may be termed specialties, and go into a number of subjects with which you will have to be familiar before getting your ticket."

CHAPTER XVII

Indicator Cards and Horsepower

"My subject this evening will be indicating cards," remarked McAndrew, as his class gathered in the improvised school room after a hard day's work in connection with lowering two of the new boilers of the *Tuscarora* in place.

"Do you know what a steam engine indicator is?" he inquired, looking at O'Rourke, who he surmised would be the first to give a reply. He was not disappointed, as that young man immediately volunteered the information that "an indicator, sir, is a nickel-plated machine that looks something like a pickle castor; you screw it into the outside of a cylinder, tie a string to its tail, let it sneeze three or four times, then unwrap a piece of paper from the outside, which you carry up to the chief engineer, who looks wise, fixes his 'specs,' and delivers the opinion that she's got too much compression, whatever that is."

"That's a fine description, O'Rourke, and shows that you are a man of keen perception, especially as to the 'look wise' part of the performance. The appearance of knowing all about it seems to attach itself to the face of every man who has an indicator card handed to him for inspection. As a matter of fact there are a great many people who look at indicator cards in this manner who don't know much more about them than any of you boys do right now. For that reason I intend to tell you something about them, so that you will not altogether belie your looks when you come to do the 'wise' act.

"An indicator, as its name implies, is used to indicate what

transpires inside the cylinder. You all know that steam enters at one end of the engine and leaves at the other; but it is what it does in the meantime which interests us most.

"One of the principal features of the indicator is a small steam cylinder, which can be connected directly to either one end of the main cylinder or the other, at will, by simply turning a three-way cock. The steam acting on the piston in this small cylinder is therefore duplicating exactly its effect on the piston of the cylinder to which it is attached at every portion of its stroke. The up and down motion of this small piston is transmitted by means of a system of small levers and links to a small pencil point, which is made to move in a straight vertical line.

"The other main portion of the indicator is the barrel, which by means of a cord attached to a specially arranged reducing gear, is given a rotary motion corresponding on a small scale, of course, to the simultaneous action of the steam engine piston. Then, by pressing this pencil point, moving always in a vertical line, against a piece of paper wrapped around the rotating drum, a figure is drawn, which, to the initiated, shows exactly what pressure in pounds per square inch is being exerted on the engine piston at every point in its stroke.

"The little piston works against a spiral spring of a tension designed according to the pressure which is expected to be used in the cylinder. On the high-pressure cylinder we would use springs of from 60 to 100 pounds tension, on the intermediate from 20 to 50 pounds, and on the low-pressure a spring of about 10 pounds tension."

Here McAndrew drew the sketch (Fig. 29) on the blackboard, and said, "This represents an ideal indicator card taken from a single-cylinder condensing engine."

"Huh!" remarked O'Rourke, after the sketch had been completed, "that looks like one of those wooden shoes that Schmidt's grandfather wore."

Schmidt retaliated by remarking that he would bet that O'Rourke's grandfather was a bog-trotter, and didn't have shoes of any kind to wear.

"That'll do," suggested McAndrew. "This is no lecture on 'Shoes of All Nations.'

"This card is what you would get off a well-designed engine. The line *PQ* is known as the atmospheric line, or the line

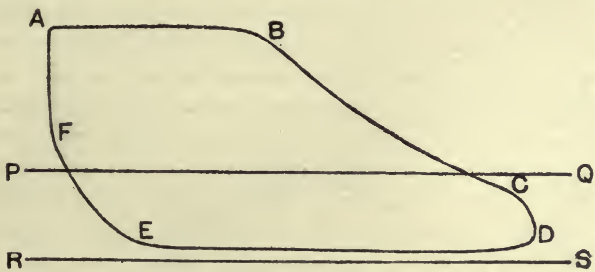

FIG. 29.—INDICATOR CARD

showing the pressure of the atmosphere. It should always be drawn on the card before making the connection to either end of the cylinder, or otherwise your card will not be of much value. The line *RS* is known as the line of zero pressure, and has to be drawn on the card with a ruler. As the pressure of the atmosphere is, as I have told you before, 14.7 pounds per square inch, it should be a distance below the atmospheric line equivalent to that pressure on the scale used for whichever tension of spring has been used in the indicator. For example, if a 30-pound spring has been used, the zero line would be about one-half inch below the atmospheric line and always parallel to it."

"What's *parallel* mean?" whispered O'Rourke to Pierce.

Overhearing the question, McAndrew said, "I am surprised that you don't know the meaning of that term. 'Parallel' means two lines that are the same distance apart at all points,

like railroad tracks, for instance; they never meet no matter how far they are extended."

"Schmidt's feet must be parallel, then," interjected O'Rourke. "He' so bow-legged that they have never met yet."

"Now referring to the figure again," McAndrew continued, "you all know that the steam is admitted to the cylinder at the end of each stroke almost instantaneously as the valve opens; this causes the pencil point to go up almost vertically as the revolving drum, following the motion of the engine piston, is then practically at a standstill while changing direction. This line *AF* on the card is known as the admission line; as the valve remains open the steam continues to rush in at the same pressure, thus making the line *AB* practically parallel to the atmospheric line. This line *AB* is known as the steam line. *B* is the point of cut-off, where steam can no longer enter the cylinder direct from the boilers. The point of cut-off varies from .3 to .7 of the stroke, according to the various conditions.

"After the valve closes, the steam in the cylinder continues to shove the piston on its travel by the expansive force of the steam. As the piston proceeds on its stroke the pressure of the steam gradually drops, so that the line traced by the pencil assumes a curved shape as shown in the diagram; this line *BD* is known as the expansion line. At the point *D* the valve opens to the exhaust, and the steam rushes out of the cylinder."

"Do they call it 'exhausted' because the steam is tired out from pushing the piston?" inquired O'Rourke.

"Very likely that's the reason," smilingly replied McAndrew.

"The live steam is now being admitted to the other end of the cylinder driving the piston on its return stroke, and the expanded steam, or 'tired' steam, as O'Rourke thinks it is, continues to escape from the opposite end until suddenly the valve closes at the point *E* in the stroke, and a certain amount

of this 'tired' steam is imprisoned in the cylinder. As the piston has not yet finished its stroke this portion of the exhaust steam is compresed in the cylinder, and acts as a spring to overcome the momentum of the piston when it reaches the end of the stroke. It thus acts very much like a bumper on a freight car. At the point *F* live steam is again admitted to that end of the cylinder, and the operation, which I have outlined, is repeated.

"The card which I have shown you is, of course, for only one end of the cylinder; the card from the other end will be of the same general shape, and the pair will look like Fig. 30":

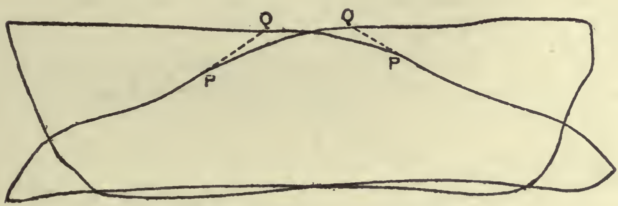

FIG. 30.—PAIR OF INDICATOR CARDS

"That looks like a pair of wooden shoes on a pigeon-toed man."

"What good are all these indicator cards?" inquired Nelson.

"That's the point I am coming to," replied McAndrew. "They are not of any use unless you can read them intelligently. An indicator card to a trained engineer serves about the same purpose as counting the pulse, taking the temperature and looking at the tongue of a sick man does to a physician. You find out what is going on inside. If there is anything wrong with the valves, or if the piston is leaking, it is shown at once on the card. The principal value of a card is, however, to tell how much power is being developed by the engine, and how it is distributed among the cylinders of a multiple-expansion engine.

"Here are some of the examples of wrong valve setting which can be detected.

"All eccentrics of a Stephenson link motion valve gear, the one most universally used in marine work, are set at right angles, or one-fourth of the circumference of the crank circle in advance of the crank, plus a small angle known as the angular advance. Now if this angular advance is too large, cut-off occurs too soon, the steam lead, or time the valve is open before the piston reaches the end of the stroke, is too great, and the opening and closing of the exhaust occur too soon; in other words, all of the functions of the valve are ahead of time, and the result is shown by a card such as I have shown in Fig. 31.

"If, on the contrary, this angular advance is too small, then all of the functions of the valve are too late, and the resulting card will be like Fig. 32.

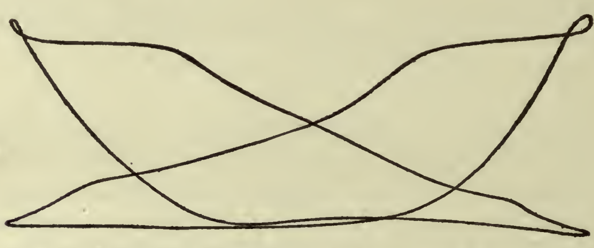

FIG. 31.—INDICATOR CARDS, WITH ANGULAR ADVANCE TOO LARGE

"The steam lap of a valve is, as you have been told before, the amount the valve laps over the steam port when the valve is in its mid-position; the general effect of such a condition is that the cut-off is too soon, the steam opening is late, and as there is not sufficient opening for the entrance of the steam, there is a certain amount of wire-drawing or the effect of passing steam through a contracted opening. This is also indicated by a drop in the pressure, which makes the steam line

get away from its parallel position to the atmospheric line. Such a state of affairs produces a card like Fig. 33.

"The opposite effect is caused in all the functions of the valve if the steam lap is too small, as shown by a card like Fig. 34.

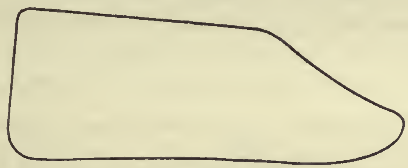

FIG. 32.—INDICATOR CARD, WITH ANGULAR ADVANCE TOO SMALL

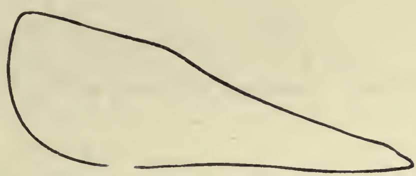

FIG. 33.—INDICATOR CARD, WITH STEAM LAP TOO LARGE

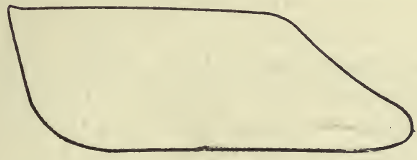

FIG. 34.—INDICATOR CARD, WITH STEAM LAP TOO SMALL

"In the layout of the valve gear the designer may have made the valve stem too long; this would result in too much steam lap on top and too little exhaust lap on the bottom, which would make the cut-off too early at the top and too late at the bottom, the steam opening on top late and at the bottom too early. Such a contingency would produce a card like Fig. 35."

"That looks as if somebody had given it a swift kick," said O'Rourke.

"Exactly so," replied McAndrew. "And if the valve stem was too short it would look as if it had received a swift kick at the other end.

"Now if the piston was leaking badly the result would be very noticeable on the expansion line, as it would not be so full as it is when the piston is tight and the steam is expanded normally. In other words the expansion line would drop below

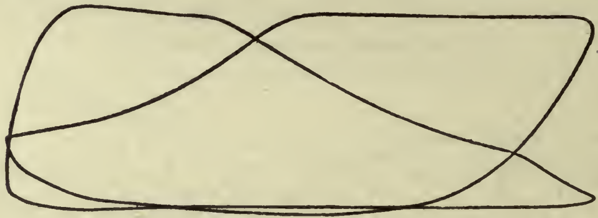

FIG. 35.—INDICATOR CARD, WITH VALVE STEM TOO LONG OR TOO SHORT

its right position on the card, showing that the pressure was low on account of the leak.

"There are many other conditions that are shown by the shape of the indicator cards, most of which can be reasoned out by understanding the general conditions affecting the steam in the cylinder. As your experience in reading indicator cards progresses you will be better able to interpret the conditions which exist.

"We now come to the calculation of horsepower from the indicator diagrams. You will remember that in the early days of this Floating School I tried to impress upon you the meaning of power; that is, that it consists of three elements—force, in pounds; distance, in feet; and time, in minutes.

"The element of distance is quite easily determined, as knowing the stroke of the engine in inches, we can, by counting the revolutions and multiplying that number by two (as it

takes two strokes to make a revolution), quite easily determine how far the piston has traveled in any given time.

"The element of time is readily determined by observations on the engine-room clock or on a watch held in the hand.

"The third element, of force exerted in pounds, is more difficult to determine, and is the only essential in the calculation which is furnished by means of the indicator card. We know that the steam enters a cylinder at a little less pressure than shown by the boiler gage, and that it leaves at a greatly

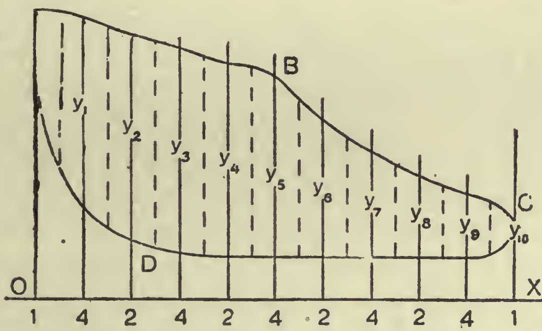

FIG. 36

reduced pressure. When we have different pressures at every point of the piston's travel, in order to determine the total pressure exerted we must take the average of all the pressures. This is where the indicator card comes into use, as from the scale of the spring used it is possible to determine the pressure exerted at every point of the stroke. To get the average pressure from an indicator card the simplest method is as follows:

"Divide the card into ten intervals, as shown by y_0, y_1, etc. Between each of these spaces draw dotted lines just half-way between the full lines. Now add up the lengths of all these ten lines, either by measuring each one separately or trans-

ferring them one after another to a strip of paper; divide the total length of all these dotted lines by 10, and the answer, multiplied by the scale of the spring, will give you the average pressure exerted on the piston.

"Another method is by what is known as a planimeter, a small instrument which usually comes with every set of indicators. By this instrument we can ascertain the area of any irregular figure. We can easily measure the length of the card, so by dividing the area in square inches by the length in inches, the quotient will give us the average height, also in inches. This height, multiplied by the scale of the spring, gives the mean or average pressure.

"Having ascertained the mean pressure per square inch, the next step is to find out the total pressure on the piston. The rule for the area of any circle is to square the diameter; that is, multiply it by itself, and then multiply that quotient by the figures .7854, which gives the area in square inches, Knowing the pressure per square inch and the total number of square inches in the piston, we multiply them together to find the total pressure in pounds on the whole piston, which is, as I told you, the last of the three elements necessary in calculating horsepower."

"What has 'drawing' got to do with figuring horsepower?" inquired O'Rourke.

"I don't quite understand you," said McAndrew.

"A guy out here in the shipyard told me only this morning that all you had to do was to remember the word 'drawing' and you could figure horsepower," argued O'Rourke.

"Oh! I see what you are driving at. You mean the word P-L-A-N, not drawing. That word has been connected with the subject ever since horsepower was invented. It is a good way to remember the calculation, providing you know what the letters signify.

P means the average pressure per square inch; L stands for the length of stroke; A is the area of the piston; N is the number of revolutions.

"It is much better to remember the method, however, by reasoning the matter out in terms of force, distance and time, as I have already told you. We want to get the whole problem into so many foot pounds per minute, then we know that dividing by 33,000 will give us the horsepower. The best way to illustrate the method is to work out a specimen for you. For example:

"A certain steam cylinder is 41 inches in diameter, the stroke is 36 inches, the mean effective pressure is 42 pounds per square inch, and the number of revolutions is 110 per minute. What is the horsepower?

"We find the area of the piston as follows:

$$\begin{array}{r}
41 \\
41 \\
\hline
41 \\
164 \\
\hline
1681 \\
.7854 \\
\hline
6724 \\
8405 \\
13448 \\
11767 \\
\hline
1320.2574
\end{array}$$

"Now multiply the area by the mean effective pressure,

$$\begin{array}{r}
1320.25 \\
42 \\
\hline
264050 \\
528100 \\
\hline
55450.50
\end{array}$$

"This gives us the total pounds pressure exerted on the piston and is the element of *force*.

"The distance the piston moves through is, of course, equal to twice the stroke, as the piston has to go up and down to make one revolution, therefore as 36 inches are equal to 3 feet, multiply by 2, and we have 6 feet as the distance moved in one revolution, and in 110 revolutions it will have moved 660 feet—this is the element of *distance*.

"The element of time is, of course, one minute, as that is the basis on which horsepower is taken.

"Now multiply the force (55450.5 pounds) by the distance (660 feet), and we get 36,597,330 foot pounds per minute. Dividing this number by 33,000 we find the answer to be 1109 horsepower. The calculations I have shown you would be all right if there were no piston rod; but as that is, of course, a necessity, we must make allowances for the area of the rod, as no pressure is exerted on that portion of the piston occupied by the rod. I should also tell you that in making the calculations the mean effective pressure per square inch must be taken as the average obtained from the top and bottom indicator cards.

"To allow for the piston rod it is customary to calculate its area the same as for any other circle, and to take only half the area of the rod from the total area of the piston, as the rod is, as you know, on only one side. Thus the area of a piston rod 6 inches in diameter is 28.274 square inches. One-half of that is 14.137 square inches. This should be subtracted from the total area of the piston 1320.25, which would leave 1306.11 square inches to be multiplied by 42 to obtain the element force, average or total pressure on the piston."

"Chief, what's the use of all this 'dope' about indicator cards and horsepower to the men that drive the engine?" asked Pierce.

"I don't suppose that it is very valuable to the ordinary everyday engine-driving man on board ship, but engineers are some-

what like lawyers in this respect. Every lawyer likes to study about the Constitution and be admitted to practice before the Supreme Court. About one in every hundred ever has occasion to use his knowledge in that connection, but he would be a poor lawyer if he didn't aim that high."

CHAPTER XVIII

Care and Management of Boilers

For several weeks there had been an enforced vacation in the Floating School, the reason being that the work of installing the new boilers on the *Tuscarora* had been rushed night and day in order to get the ship out in time for the heavy trade in the autumn months. The members of the school had been kept so busy that they had but little time for study, and Chief McAndrew, of course, had so much to attend to in the thousand and one details a chief engineer has to think of that he had no opportunity to give the young men any attention. The repair work was finally declared completed; a dock trial had been held and the new boilers found satisfactory. The ship was to sail early the next morning; O'Rourke and Schmidt had been given two hours' liberty, in which time they had taken a fond farewell of their Fishtown girls. Nelson and Pierce denied that they had any particular sweethearts in Philadelphia, but they had enjoyed their stay in that place so much that they were somewhat loath to leave.

A full crew had been shipped for the engineer's department, and the Chief had so arranged it that all of his pupils would be in one watch. Much to his gratification, Jim Pierce had been promoted to be an oiler. Gus Schmidt had been given a boost by being signed as a water-tender, which led O'Rourke to remark that it must have been because he was so fond of water. Nelson and O'Rourke were still retained as firemen, but the Chief had promised them that if they paid close attention to business they would be given the first vacancies as water-tenders.

The Chief, of course, having three assistants, stood no watch, and he very kindly agreed to continue his classes at such

intervals while the four aspirants for licenses were "off watch," as it might be convenient for him to spare them a little of his time.

The ship proceeded down the Delaware River on her way to New York, and as the four young men stood the 8 to 12 watch, McAndrew said he would give them an hour or so of his time that afternoon. The school was quite a mystery to the other men in the engineer's crowd, and some of them were inclined to be a little facetious about the four "high brows," as they termed them. However, as information regarding the school was imparted to them almost simultaneously with an exploitation of the fact that O'Rourke had been awarded several prizes as a heavyweight boxer at an East Side resort, the tendency to sarcastic remarks rapidly dwindled.

On addressing his class that particular afternoon, McAndrew stated that as the ship was now at sea, and was to continue on her regular duties, he would take up the subject of the care and management of machinery, and naturally would begin at the boilers.

"Before starting fires under boilers," he said, "we must first examine everything connected with them. See that all stems on the stop valves, check valves and blow valves are oiled, and that the valves can be worked freely. The safety valve gear should be put in good working condition, and the valves raised slightly off their seats. The air cock at the top of the boiler should be opened, or if none such is fitted, open the top gage-cock in order to allow the air to escape. See that the grate-bars are all in place, that the damper works freely, that the handhole and manhole plates are set up tight, that all necessary fire tools are on hand, that the bunker doors are opened, and that the surface and bottom blow valves and drain cocks are closed tightly.

"If steam has not been raised on any of the boilers so as to allow the running of the pumps, the boilers should be filled by

means of a hose from the deck, through the top manhole plates. It is only necessary to fill the boiler up to about two-thirds of a glass, as the water 'swells,' as the term is, when heat is applied to it. That is, in an ordinary boiler the water expands in volume as it is heated until it rises 2 or 3 inches in the glass. If no hot coals from another boiler are available, after throwing some coal on the bars, it is usual to start a wood fire at first and throw on a light covering of coal after the fire has commenced to burn freely. Soft coal catches fire comparatively easily, and so your fires will soon be burning in all the furnaces. In Scotch boilers great care must be taken not to force the fires and raise steam too quickly. It takes a long time to get the heavy shell plates warmed through uniformly, and if steam is raised too hurriedly the seams will begin to leak on account of the unequal expansion. For that reason it is usual to take from six to twelve hours' time in raising steam. One of the great advantages of watertube boilers is that steam can be raised rapidly without doing them any harm, as from their construction the water is rapidly circulated in all parts, and a uniform temperature throughout is easy to maintain. For that reason it is safe to raise steam in the average watertube boilers in a half hour if deemed necessary.

"The great disadvantage of all Scotch boilers is the large amount of water underneath the furnace which will not circulate naturally, and consequently remains quite cool even after steam is formed. To overcome this there are several patented devices which can be fitted to Scotch boilers, which will automatically circulate the dead water under the furnaces until the temperature is raised to very near that of the water above the furnaces. On ships which are not provided with such apparatus it is customary, if steam is available from another boiler, to run the auxiliary feed pump slowly, with its suction connected to the bottom blow, and its discharge enter-

ing the boiler through the regular feed pipe. This starts up a forced circulation and greatly facilitates the raising of steam.

"As steam begins to form slowly it will be first indicated by a slight hissing noise of the air escaping through the air-cock or the gage-cock. This air should be allowed to blow until clear steam can be seen escaping. Then the safety valves should be lowered, all cocks closed, and the steam pressure allowed to rise slowly, not over a rate of ten pounds an hour if there is no particular hurry about the operation. When the pressure rises to, say, 100 pounds, the auxiliary stop valve should be opened and steam admitted to the auxiliary line for the purpose of running the various auxiliaries.

"Having raised the steam to the working pressure, and put the boiler in service, the object of the engineer should be to keep it up to its highest state of efficiency; that is, to get out the most steam for the least expenditure of coal. To do this requires constant care and attention, for, like human beings, boilers respond readily to good treatment and rebel at harsh treatment. There are three principal things to do, which, if attended to intelligently, will keep a boiler in good condition. The first of these is to feed it with pure water; second, do not subject it to sudden changes of temperature, and, third, fire it properly.

"If these three maxims were lived up to there would be but little trouble. Unfortunately, however, they are difficult of accomplishment, and for that reason the average boiler is beset with many ills. Most of these arise from the quality of the water fed to the steel workman. In spite of precautions grease will get in the feed water from the condensed steam; acids will be generated by the contact with the copper condenser tubes and feed pipes, and salt water will get in through leaks in the condenser tubes and pipe connections, and occasionally salt water will have to be fed to make up losses. It is these foreign elements in the feed water which make all the trouble."

"Yes," broke in O'Rourke, with a meaning glare at Schmidt, "and my father always used to say that it is the foreign elements that make all the trouble in this country."

"Is that so?" sarcastically replied Schmidt. "I'll bet it wasn't many days before you were born that he was tramping through Castle Garden himself."

"I don't suppose that any of us is eligible to join the Sons of the American Revolution," said McAndrew; "but that cuts no figure in this land of the free.

"As I was saying before being so rudely interrupted, if it were not for the impurities which get into the boilers the engineer would have but little trouble in keeping the interior surfaces clean. To counteract all these impurities is one of the main parts of an engineer's duty. Hence one of the first things to do is to ascertain how much salt water slips in from one source or another. Since steam vessels first plied the oceans, every one has been fitted with an instrument known as a salinometer—not 'salometer,' as I have heard O'Rourke term it. This word means literally salt measure, and at that it does not express its use correctly.

"Salt, of course, is one of the principal solids in salt water, but there are enough other chemicals in it to start a small drug store. In case any one ever asks you what salt water does contain you can refer to this analysis of the average sea water, as it contains the following parts in 1000:

Water	964.745
Chloride of sodium (common salt)	27.059
Chloride of potassium	.766
Chloride of magnesium	3.666
Bromide of magnesium	.029
Sulphate of magnesia (Epsom salts)	2.296
Sulphate of lime (plaster of paris)	1.406
Carbonate of lime (chalk)	.033
	1000.00

"Some chemists state that there is also a small quantity of gold in sea water; but I wouldn't advise any of you to buy any stock in a company formed for the purpose of getting gold from that source.

"Although the instrument I have referred to is called a salt measure, its real purpose is to determine how much solid matter is contained in the water. By adding up the amounts of all the solid ingredients in sea water you will see that they foot up approximately 1/32 of the entire weight of the water. That is, in 1 pound of salt water there would be 1/32 pound, or ½ ounce, of solids. Hence all salinometers are graded on that basis; 1/32 means salt water as drawn from the sea; 2/32 means twice as much solid contents as ordinary sea water, and so on.

"With every salinometer there is a small glass instrument weighted with shot known as a hydrometer. This instrument is usually graduated in divisions known as 32nds, which is based upon the principle that a floating body displaces an amount of water equal to its own weight. Hence the heavier or denser the water it floats in, the higher will be the portion out of the water. That is the reason that it is easier for a man to float in salt water than it is in fresh water. I have told you before that water expands when heated, hence its weight or density varies with its temperature. Therefore, to use the hydrometer correctly, the water to be tested must be at the same temperature for which the scale on the hydrometer is adjusted.

"On most hydrometers there are three scales shown—one at 190, one at 200 and the other at 210 degrees F. The method of testing is to open the cock and allow the boiler water to fill a brass vessel, known as the salinometer pot; if it is below 190 degrees F., as shown by the thermometer, admit sufficient hot water from the boiler to heat it up to one of the three temperatures shown on the scale. Then put in the hydrometer and

observe how high it floats on the temperature scale corresponding to the temperature of the water. If you should hear some one say that the water is 2¼ or 2½, it would mean 2¼ thirty-seconds, or 2½ thirty-seconds, as the case might be.

"I have devoted some time to telling you about the salinometer and how to use it, but I will tell you very briefly that it is not of much value nowadays, as that method is too crude for modern usage. You might as well weigh drugs on a hay scale, so far as accuracy is concerned. There is in use on a number of ships a chemical process for determining accurately the amounts of the principal ingredients in boiler water; the apparatus is so simple that if the directions are closely followed any engineer can use it.

"Very few marine engineers allow salt water to be used for make-up feed in these days, hence it is not so essential to guard against scale-forming ingredients in the water. The principal causes of deterioration, such as rust and pitting, are due to the acids which get into the boiler water and thus encourage galvanic action."

"What's that?" blurted out O'Rourke.

"I thought you wouldn't understand it, O'Rourke, and so I used the term to arouse your curiosity. The word 'galvanic' is derived from the name Galvini, an Italian scientist, who first discovered that an electric current is set up by the action of one metal on another. You all probably know something about the ordinary battery used for generating an electric current. This consists of a glass jar in which are immersed pieces of zinc and copper; you have probably noticed that the liquid in which they are immersed is slightly blue in color, this being caused by putting in some crystals. The object of these crystals is to form sulphuric acid in which the chemical action between the copper and zinc is readily started, with the result that an electric current is generated; the further result is that the zinc is gradually eaten away by this action, and after a

certain length of time has to be removed. Now if these two metals had been placed in a jar containing pure water there would have been none of this action taking place.

"Here, then, is the secret of boiler pitting and corrosion; the whole boiler, if the water is allowed to get in acid condition, becomes like an immense battery, or rather a collection of small batteries, as this action will take place between different parts of the steel of which the boiler is constructed as well as between a brass feed pipe and the boiler shell, only, of course, it will not be so rapid. Hence it is that for years past baskets containing zinc have been suspended in different parts of the boiler immersed in the water, as the zinc is much more easily attacked by galvanic action than are the steel and iron of the boilers. The zinc is therefore eaten away, and theoretically, at least, the various parts of the boilers are spared. Later investigations on the subject have developed the fact that even the use of zinc is not the best step to be taken, as that is simply remedying the effects without removing the cause. In other words, it is similar to trying to cure a headache for a drunken man after every night's jag instead of making him stop drinking the booze and preventing the headaches."

"I can understand that argument all right, all right," said O'Rourke, who had been, for him, paying very close attention to McAndrew's remarks.

"These later experiments which I refer to have been directed towards preventing the boiler water from getting into an acid condition, and thereby stopping galvanic action and rust. It is a well-known law of chemistry that alkalis will counteract or neutralize acids. Plain soda ash, or sal soda, as it is called commercially, is one of the best and cheapest of the alkalis obtainable, hence that is the material best used for counteracting acids in boiler feed water. It is also used to "kill" grease and oils which get into the feed water. Soda and zinc have for many years been relied upon to correct all

of the evils which beset marine boilers, and yet they continue to rust, pit and eat away.

"By a long and continued series of tests recently held, some curious facts have been learned regarding the use of soda in feed water. One is that a small amount of soda, about one-tenth of 1 percent, is less corrosive than neutral water, or water that is neither acid nor alkaline; another is that water above one-tenth of 1 percent, and up to 2.6 percent alkaline, is really more corrosive in its effect than water in its neutral state. Finally, these experiments demonstrated that water containing 3 percent and over of the alkaline solution is absolutely non-corrosive.

"But the addition of such much ordinary soda to a boiler in which necessarily there are some oils or grease, will invariably cause violent foaming, or priming, as it is sometimes called. This is prevented by mixing with the soda certain proportions of glucose and a substance known as 'cutch,' which is a form of tannic acid. These ingredients tend to prevent foaming and the formation of scale. These materials are combined in standard makes of boiler compounds, and if they are properly used there is little doubt but that pitting and rusting will cease to a great extent. In order to get a 3 percent solution of the boiler water it is necessary to add about 5½ pounds of this compound for each ton of water in the boiler.

"Heretofore the care of boilers has been very much on the order of quackery in dosing the human system with all kinds of patent nostrums. There are but few medicines given by doctors which really accomplish any good, and they have been developed by experimenting. Many a good man has lost his life by having various kinds of 'dope' tried out in his stomach, and many a good boiler has met an untimely end by ignorant treatment. Now the 'boiler doctors' are really studying the subject, and from this time on boilers will be given better treatment. You young men are coming into the business at a

time when the new methods of treating boilers are being perfected, and I predict that by the time you get in charge of steam machinery you will know much better how to take care of your boilers than engineers have in the past.

"No matter how well you treat the boilers while running they must, at certain periods, be given an overhauling, and at such times the greatest care and attention must be given them.

"The fire surfaces must be thoroughly cleaned and all deposits of soot brushed off. The water surfaces must be given the closest attention, and particular care taken to clean all dirt and scale off the crown sheets or tops of the furnaces. As you all know, this is no easy job, especially with Scotch boilers, as the spaces in which a man has to work are necessarily cramped, the air he breathes is vile, and there is every condition which would make him shirk the work, yet if the cleaning and scaling are not done properly the boiler and the coal pile will suffer alike.

"To give you an idea of the bad effect of even a slight amount of scale on the heating surfaces of a boiler, you will be surprised, I know, to learn that a hard scale only one-twentieth of an inch thick reduces the efficiency of a boiler 11.1 percent. That is, if a boiler is scaled up to that thickness on its heating surfaces, for every hundred tons of coal consumed there will be an absolute loss of 11.1 tons in the steam-producing effect."

"That would very nearly pay the fireman's wages, wouldn't it?" inquired Nelson.

"Yes, and more than pay them, so you can see the necessity for keeping boilers clean.

"Soot on the fire surfaces has almost as bad an effect, so you can understand how important it is to blow the tubes while running."

"The company ought to pay us extra every time we blow tubes," suggested O'Rourke.

"That's where you are wrong, as usual, O'Rourke. Employers in these days pay people to look after their interests in every way, and because a man is a fireman doesn't mean that he is for the sole purpose of shoveling coal in the furnaces. It is the fellow who thinks what he can do to save his employers money by keeping the particular piece of machinery which he is handling up to the highest state of efficiency who gets promoted and carries away the most coin on pay day.

"When cleaning boilers it is very important that all the valves and attachments be given a thorough inspection and put in first-class condition. All screw valve stems should be oiled with cylinder oil and graphite, glands repacked, safety valve lifting gear oiled and made to work easily. Small pin-head leaks should be touched up with a calking tool as soon as they are noticed. A leak in a boiler should be treated in accordance with the old saying, 'A stitch in time saves nine.'

"Many people have the idea that a fireman to be successful need only be sufficiently strong to stand the heat and shovel coal in the furnace for a period of four hours at a time. That is a great mistake, as the successful operation of marine machinery depends more upon skillful firing than upon any other part of the business. No man can be a successful marine engineer unless he knows how coal can be burned most efficiently, and sees to it that what he knows in that line is put into force by the gang in the fire-room. The average fireman if left alone to follow his inclination will nearly always fill up his furnaces to the top, under the mistaken idea that a 'crown-sheeter,' as it is termed, makes the most steam. The average fire-room watch will, if not instructed otherwise, as soon as they come on duty clean their quota of fires, usually about one of every three, fill up the furnaces, then sit down and smoke for an hour or so. The boilers will also smoke under such treatment and make about as little steam as possible.

"In order to get the best results the following rules should be stuck to closely:

"Carry the fires for natural draft not over 8 or 10 inches thick; if forced draft is used they should be about a foot thick.

"Put on only two or three shovelfulls at a time in each furnace—throw it on quickly and spread it evenly over the fire.

"Never open more than one furnace door at a time, and close it just as soon as possible.

"Never throw in any lumps larger than a man's fist; have the coal passer exercise himself by using a coal maul on larger lumps before putting the coal in the furnace.

"Only use a slice bar to remove clinkers or ashes, and to keep the fires bright from the under side.

"Keep the ash pans clear at all times.

"Clean only one fire at a time, and so regulate the periods between cleanings that they come regularly, if the coal is of uniform quality; otherwise clean them whenever they get dirty.

"If the draft is strong and the coal very fine and dusty, sprinkle a little water on the coal.

"Keep the fires of even thickness by the use of the hoe or rake; level them off every other time that coal is thrown into the furnaces.

"Have each watch get out its ashes before being relieved, otherwise there will be a scrap with the next watch.

"In general, have everything done in the fire-room with some snap."

"In other words," butted in O'Rourke, "put some ginger into the work."

"Yes, that's it; let the 'ginger-snap' be the motto of the fire-room."

"It's more likely to be the hardtack," suggested the Hibernian.

"That's true, too, unless you use your brains as well as your muscles."

"Won't you tell us something about a water-tender's duties?" asked Pierce, who was feeling the responsibility of his new job.

"I was just coming to that," replied McAndrew. "The success of the fire-room depends largely upon the water-tender; the engineer of the watch may issue all the instructions about firing that he wants to, but he can't be in the fireroom all the time to see that they are carried out. Hence a rattling good water-tender is very necessary. Primarily he wants to be a man of nerve, quick to think and quick to act, and it's not a bad asset for him to be able to lick any fireman or coal-passer in his watch. Not that he should resort to tactics of that kind—far be it from me to suggest any such cruel procedure—but I have noticed in my several years of climbing that a water-tender who is handy with his fists generally keeps the ginger in the ginger-snap with his men. His principal job is to keep his mind on his duties during every minute he is on watch, and to keep his eye on the gage-glasses at least once every minute.

"He must also see that the furnaces are charged regularly in accordance with his instructions; that the fire-room is kept clean; that the coal is tallied; that the ash pans are hauled and the ashes blown out, and, in general, that all the routine duties of the fire-room are kept up. Ordinarily he should see that the water is maintained at about half a glass, and that the feed is so regulated by the check valves that it remains steady at that height if possible. As long as a boiler is under steam and the engines running, the feed should never be entirely cut off—no boiler has ever yet been blown up by having too much water in it, so there is no danger to the boiler even if you do put too much water in it—sometimes there is danger to the engine on account of foaming, caused by too much

water. In general, the all-important thing to guard against in tending water is that there will always be water showing in the gage-glasses. Low water is the cause of 90 percent of all boiler explosions, and in nearly every case it is a direct result of carelessness.

"In case the water does get out of sight, as it will do at times in the best regulated fire-rooms, the first thing not to do is to get excited. No boiler ever has blown up immediately after the water has dropped out of sight. Keep cool yourself and try to cool the affected boiler. If you feel positive that the water level is only a little below the bottom of the glass, open the check valve wide and hold your breath. You may, during your first experience, think that it is taking about one month and ten days for the water to show up, but in reality it is usually visible in four or five minutes; then you can begin to breathe again. If, however, the water is out of sight, and you don't feel positive of the last time you saw it, close the damper; put up the ash-pit doors; shut off the main and auxiliary stop valves and the check valve and throw wet ashes or fresh coal over the fires to deaden them. Never haul the fires out until they have been deadened or extinguished by water, as stirring them up temporarily causes an increased heat, which might prove disastrous.

In case of low water, the first thing, of course, is to try and remedy it by cutting out the boiler affected, as above described. But the water-tender must remember that the other boilers are still steaming, and he must not neglect to see that they are properly looked after, notwithstanding the temporary excitement on account of the crippled boiler. To sum it all up, a good water-tender must combine attention to business, quickness to act, and imperturbability of the highest degree."

This last qualification simply stunned O'Rourke, and while he was trying to recover from the shock the length of the word had given him, the Chief said: "I knew that would hold

you, O'Rourke; but don't be alarmed, it simply means the quality of not getting rattled; you have your share of it.

"When the ship arrives in port and the boilers are to be out of use for several days, the fires should not be hauled, but simply allowed to die out gradually, so that there will be no sudden cooling of the boiler shell. It is usually advisable to give them a good blowing off from both the bottom and surface blows. After the steam is gone they should be pumped up full with fresh water, putting on a small pressure of 5 or 10 pounds to make sure that they are filled up. They should never be emptied by blowing off, as that causes too sudden cooling. If the boiler is to be cleaned the fires should be allowed to die out and the water pumped out after the steam has disappeared.

"If the boiler is to stand full of water for any length of time, the water should be made alkaline, so as to prevent corrosion as far as possible.

"If the ship is to be laid up great care should be paid to putting the boilers in such condition that they will not deteriorate. The grate-bars and furnace fittings, ash pans, etc., should be taken out and stacked up in the fire-room, out of the way but in a convenient position to be replaced. The interior of the furnaces, the combustion chambers and the tubes should be thoroughly brushed and cleaned to remove all soot and ashes. They should then be given a coating of black oil all over. The inside or water surfaces should be thoroughly cleaned and then thoroughly dried out by starting a light wood fire in the furnaces for a few moments, and by burning pans of charcoal inside the boiler. Some people prefer to fill the boilers up solid with water when they are to be laid up for several months, but I prefer to have them laid up dry as I have described. All the valves should be overhauled; put in good condition, and the valve stems coated with heavy oil or grease. A hood should be placed over the smokestack in order to keep the rain from leaking down and running into the up-takes.

"I could tell you lots more about the care of boilers, as you must remember that it is almost an inexhaustible subject. However, I have touched on the high spots of care and management, and you must learn much more by reading and from experience, the greatest teacher of all."

"They say old Experience is a hard teacher," suggested O'Rourke.

"You will find that he is if you don't follow the rules of his school."

"What are they?"

"His schools on board ship require diligence, energy and sobriety; if those three are lived up to you will find the old fellow is rather an easy teacher."

CHAPTER XIX

Care and Management of Engines and Auxiliaries

The *Tuscarora* arrived in New York and was loaded for her first trip South after the extensive repairs she had undergone. The chief had, of course, been so busy attending to getting the vessel's stores, etc., ready for her regular trips that he had paid no attention to his class other than to caution them to keep on with their studies and to learn as much as they could from observation, keeping in mind what he had told them about the various parts of the machinery.

There was a new second assistant by the name of Davis on board, and he had been placed in charge of the boilers. Coming into the fire-room suddenly one day he found O'Rourke delivering a lecture to a couple of coal passers on how steam was generated. "This blatant heat," he was saying, "is what makes you fellows hustle out the coal; it's like shoveling snow in the East River to make the tide rise; you don't seem to get a run for your money until all of a sudden—'biffo,' the steam shows on the gage!"

Davis could stand it no longer, and said, "Cut that out, O'Rourke, and get down to work—what do you know about steam, anyhow?" This highly incensed the shining light of the Floating School, and he replied rather impudently that he "was only trying to give these ginks a little scientfic dope." Later in the day O'Rourke complained to the chief that the second assistant had cut short his efforts at enlightening the coal passers on matters he had learned at the school, but he was told to pay more attention to his work and not to bother

with imparting his knowledge to an unappreciative audience.

The ship sailed from New York at her scheduled time, and was soon bucking into a southeaster as she headed down the coast. It cleared off the next day, and as everything was working smoothly the chief rounded up his class that afternoon, all of them being off watch, and proceeded to give them some further instruction.

He began his remarks by saying that it was a most unusual thing for a chief engineer of a vessel to take time while his vessel was underway to be holding a school for his men, but as he had only a little further to go in his remarks he was determined to finish the job up, even if he did have to defy all precedents.

"Having told you something about the care and management of boilers, I propose this afternoon to give you some hints on the care and management of the main engine and the various auxiliaries in the engine room.

"An engineer standing a watch at sea has so many things to attend to that to enumerate them all would fill a book in itself. Probably no other business requires so much alertness and quick acting and thinking as a marine engineer is called upon to do in the proper performance of his duties. Every faculty which God has given him is called into use. Unlike locomotive and stationary engineers, he must never allow his engines to stop for days and days at a stretch. A locomotive will be driven for five or six hours and then run into a roundhouse for a rest; a stationary engine will be run for ten or twelve hours and then stopped; but it is very seldom that a marine engine is ever stopped or even slowed down in a voyage lasting very often a week, or even two weeks at a time. To do this successfully requires the highest degree of skill, and above all things the closest attention to even the most minute details, as the derangement of even a very small part of an engine often results in a serious breakdown at a critical

moment. Remember, young men, that to be successful in your business as an engineer there is no detail about the entire mechanism of a ship that is too trivial to demand your closest attention.

"Preparations for getting underway for a long trip at sea should begin early in the morning of sailing day. If repairs or adjustments have been made during the stay in port, the engineer should personally see that every set-screw on the moving parts is set up tight; that all the bearings have been oiled around by hand; that all oil cups are filled; that the sight-feeds are properly adjusted and in working condition. To make sure that all parts of the main engine are clear, it is well to turn the engine at least once clear around, either by hand or with the jacking engine. After this is done he should personally see that the worm of the turning gear is thrown out of gear; failure to do this has cost many a man his job.

"The first thing to do is to start the circulating pump slowly and get the condenser cooled off and ready for the exhaust steam. An hour or more before time to start, depending upon the size of the engine, steam should be admitted slowly to the steam jackets around the cylinders, if there are any, if not steam can be let into the cylinders direct by cracking the throttle slightly and opening the by-pass valves. All drain valves from cylinders and valve chests must be kept open to the condenser, as steam striking the cold cylinder walls is immediately turned into water, and should be allowed to drain into the condenser.

"The warming up of large iron castings must be done slowly and thoroughly—never make haste in this process unless in a great emergency. After the cylinders are too hot to bear your hand on them, and having ascertained from the people on deck that sufficient mooring lines are out, steam may be admitted to the engine very slowly at first, and the turns gradu-

ally increased to not more than half-speed. The reversing engine should be tried back and forth a number of times to see that it works satisfactorily, and to see that the main engine will run well in the backing gear. The water service should be started. The drain valves should be kept partly open all the time that the engine is being warmed up, and, in fact, they should not be closed altogether until the vessel is underway from the dock for at least ten or fifteen minutes.

"Before sailing the chief engineer has, of course, satisfied himself that all necessary stores are on board; that the oil tanks are filled up, and that all wrenches and other tools for making quick repairs or adjustments are in place and easy of access.

"Everything now being ready, and the captain advised of that fact, the engineer stands by the throttle, posts a man at the engine-room telegraph, which has been previously tried and found to work satisfactorily, and awaits the starting signal. All signals from deck must be answered promptly, as in working away from the dock and through the crowded harbor any delay whatsoever in quickly working the engine as directed would be dangerous. Full speed is seldom ordered until the vessel is well clear of the harbor, but when it is rung up the throttle should be opened only to such an extent that the engine will just use up all the steam that the boilers will make, and will maintain a uniform number of revolutions. Fluctuations of the steam pressure should be avoided as much as possible, and so far as he is able the engineer on duty should strive to carry uniform boiler pressure, revolutions and vacuum.

"The first few hours of a run the man on watch should be unusually alert in feeling bearings, especially those which may have been recently adjusted, in order to detect the first sign of unusual heat. When a bearing starts to warm up it gets 'red hot,' as the saying is, in very short order, and should be

given instant attention. The causes of hot bearings are in most cases due to being set up too tight or else from insufficient oil supply. Occasionally heating is due to the presence of grit, but that can only result from rank carelessness in not having the bearings sufficiently covered up or otherwise protected when the engine is not in use."

"How do you cool a hot journal without stopping the engine?" inquired Nelson.

"Put cold water on her, of course, the same as you would cure a headache," volunteered O'Rourke.

"That's the very last thing you should do," continued the chief. "The first thing is to give it a large dose of oil, and in nine cases out of ten you will find that it will gradually cool off from that treatment. If it persists in heating up after you are sure that it is getting plenty of oil get out the proper wrenches and slack off the nuts a trifle. This generally accomplishes the object sought, but if even that method fails then resort to the water service, as sparingly as possible, but just enough to keep down the heat. If the ship was running in fresh water the effect would not be so bad, but salt water on a bright journal is harmful."

"I get you, chief," broke in the effervescing O'Rourke. "Curing a hot bearing is just like curing a man of a stomach ache. If it isn't very bad give him a dose of castor oil; if it gets worse put on a mustard plaster; if that don't work give him an injection of fresh water, not salt, as that would hurt him."

"Your powers of comparison are certainly well developed, O'Rourke, but I fail to see the similarity between slackening up a bearing and putting on a mustard plaster."

"Well, if that mustard plaster attends to its business all right the man will want to slack it up, you can bet."

"Chief, will you please give us some points on oiling," suggested Pierce, who was feeling the responsibility of his new job.

"I was just coming to that important subject," replied the instructor. "Oiling, like water tending, is a very important job on board ship. Although people refer in a slurring manner to the 'greasers' there are few jobs anywhere which have the importance of a marine oiler. A little inattention to his duties may result in doing great damage to the machinery, and may even stop or cripple the ship. An oiler in his rounds must be as regular as clock work, and constantly on the alert with his senses of feeling, hearing, seeing and even smelling. To a trained oiler all these senses come into play. By feeling of revolving crankpins, eccentric straps, main journals, etc., with his hands he can tell instantly if any of them are overheated, or even if they show a tendency to heat. To his sensitive ear the first discordant noise, even the slightest squeak, will indicate that some bearing or journal is running dry and needs immediate attention. His eyes must be sufficiently keen of vision to see minute and almost invisible drops of oil passing down the tubes of automatic oilers, and at times to discern even the slightest sign of smoke, which would indicate an overheated bearing. His sense of smell is called into play to detect the first indication of overheated oil or grease."

"What about his sense of humor," inquired Schmidt.

"Every oiler must have that sense well developed also, as his main object is to prevent any squeaks or groans from the bearings under his charge.

"In giving advice to you on oiling I want first to warn you against putting too much dependence on automatic oiling gear of any kind. Such apparatus is all right when it works well, and I must say that it does work well for 99 percent of the time; but there is always that small percentage of the time when it does not work well that you must guard against. A change in the temperature of the air surrounding a needle valve on oil reservoirs will often change the adjustment of the drip, so that the bearing to which it directs the flow of oil

will not receive a sufficient quantity and become heated. The same trouble might be started by a small speck of dirt or grit getting under the valve. Therefore these contrivances must be given very close attention.

"Many engineers prefer the old-fashioned wick feeds, as they are much more positive in their action, although not quite so easily adjusted.

"Most oilers, and especially beginners, use entirely too much oil, both from oiling by hand and from the automatic feeds. However, this tendency is quite easily regulated by the system of putting every man on an allowance for his watch. The good oiler usually finds his allowance to be ample, whereas the negligent man and the inexperienced man have to hustle to keep things running cool on the amount given them.

"A routine should be established, the time between oilings being regulated to suit the speed of the engine and the necessity for the oil. Usually crankpins and eccentric straps should be oiled by hand once each twenty minutes; the main journals, link gear, etc., once each half hour. An inspection of the thrust bearing, spring bearings and stern tube gland once each half hour is usually sufficient. Piston rods and valve stems should be swabbed every half hour, but as little oil as possible should be used each time, as it is by this means that oil gets inside the cylinders, is carried into the condenser and then pumped into the boilers. This is an evil that must be guarded against as much as possible.

"On many modern ships no oil whatever is used to lubricate the main engine pistons and valves; if any lubricant is necessary many engineers use graphite mixed with water. As a matter of fact in engines using piston valves, internal lubrication is not absolutely necessary. The cylinder walls are always at a less temperature than the entering steam; consequently some of the steam is condensed, and the water formed by this condensation acts as a lubricant.

"On the smaller engines, used as auxiliaries, such as pumps, blowers and dynamos, internal lubrication seems to be more of a necessity, and it is by this means that oil gets into the feed water and later into the boilers. The introduction of the steam turbine for driving dynamos and pumps does away with this danger, as, of course, no oil is necessary for the interior of turbines.

"Many engineers prefer to use grease, or compound, as it is termed, on small journals, and on those which have but little friction. Cups, known as compression cups, are screwed to the caps of such journals, and the oiler, by simply giving a small twist to the screw top on the cup, forces enough grease on the journal to last sometimes for several hours. Some engineers use grease for thrust bearings and tunnel bearings, but it is more economical to use oil. On well-designed thrusts the collars on the shafts are made to run in a bath of oil, which is kept cool by salt water circulated through coils in the bottom of the bearing.

"Oil should be caught in the drip-pans and passed through oil filters, of which there are several good types on the market, after which it can be used over again.

"It takes experience to make a good oiler, but, of course, you cannot get the experience without actually doing the oiling. In your first attempts you will do well if you only take the bark off your knuckles, and perhaps lose a finger nail, while feeling the crankpins and eccentric straps. This is a very important part of his duties and can be learned only by practice. One good rule to remember is never to feel a rapidly-revolving piece of machinery that is running toward you; wait until it starts to go away from you and then feel it very quickly. No day-dreamer can be successful, as feeling of crankpins, etc., requires quick action. Wherever it is practicable on fixed bearings use the backs of your fingers to feel with, as they are more sensitive to heat than the hardened working surfaces of a man's hand."

"Schmidt ought to use that nose of his, as they say he is very sensitive about the length of it," suggested O'Rourke, who, for him, had been silent for a long time.

Schmidt retaliated by saying that it would never do for O'Rourke to use his cheek for feeling journals, as the metal would have to be red hot for him to even notice it by that method.

McAndrew called them both down hard for making such personal references, and said that oilers were supposed to be courteous to one another. If they are not there might be all kinds of trouble when relieving one another as the watches changed. "The man about to be relieved," said he, "must have all his oil reservoirs filled up and all the bearings and journals under his care running cool, or otherwise the oiler coming on watch could refuse to relieve him.

"I hope," he continued, "that O'Rourke and Schmidt never have to relieve one another from oilers' watches, as I am afraid they would both be standing double watches the greater part of the time."

"Chief, won't you put us onto some of the duties an engineer has to do in port?" suggested Schmidt, who was probably the most eager for knowledge of any in the class.

"Certainly," replied the general instructor. "The first thing most of them do is to beat it for their own homes, or someone else's home, according to circumstances. Of course, that is natural, as a man who stands engine-room watches for a week or more at a stretch, is mighty glad to hit the beach and stretch himself out in a four-poster at least one night in ten; but, seriously speaking, there are many important things which the engineer's gang must do before sailing day arrives again. Nowadays any repairs involving machine work of any description is put into the shops, as the engineer's force usually has neither time nor the necessary tools for making any very extensive repairs. The work most usually

performed in port might be divided up under four headings. Cleaning is one of the first things to perform; adjustment of bearings must be attended to; making new joints and packing of stuffing-boxes must be performed, and examinations of the interiors of cylinders and the auxiliaries must be made periodically. These four divisions of work probably constitute nine-tenths of the duties performed in port.

"As soon as the jingle-bell is rung, signifying 'through with the engine,' the boys should be set to wiping the engine down and cleaning up the floor plates. Some engineers like to have a small injector so fitted and connected up that it can be used to wash down the bed-plates and bilges with hot water; but I don't believe in squirting salt water indiscriminately about an engine room, as it is bad for the bearings and bright work. Gaskets, made of hemp, loosely laid up, should be laid across both ends of all the principal journals to keep out any dirt or grit which might be around while the engine is not in use. During the stay in port, bulkheads should be scrubbed if they have become dirty, storerooms cleaned out and put in good order, bilge strainers cleaned thoroughly, the bilges themselves cleaned and kept well painted, the filtering material renewed in the feed tank, and in a general way the whole department given such cleaning, painting and renovating as cannot well be done while the machinery is running.

"The adjustment of bearings is probably one of the most important duties for the engineer and his assistant. If a bearing runs a little slack and develops a slight pound it should be carefully readjusted, or if there has been a tendency for any particular bearing to heat up during the trip it should be examined, and if necessary overhauled and readjusted while the ship is at the dock."

"Why are they always monkeying with the crankpins on this ship?" asked O'Rourke. "It seems to me," he continued, "that that is all one of the assistants does while this ship is

at the dock. I see him running around with something that looks like a handful of spaghetti, and he is always saying that he has got her down to 29, or some number like that. You'd think he was running a keno game. He ought to——"

"Well, O'Rourke," interrupted the chief, "if you're running this talkfest I'll quit and let you take the chair."

"I'm through," meekly replied the Hibernian, realizing, for once at least, that he was sat upon.

"Bearings lined with white metal are now almost universally used," said McAndrew, after re-establishing himself as boss of the school room. "These wear down considerably during long-continued runs, and consequently must be adjusted more often than the old-fashioned bearings of solid brass. In the early days it was the test of a good engineer to make adjustments by chipping and filing down the edges of the brasses uniformly, as that was the method then in vogue. All bearings in these times have pieces of brass, known as distance pieces, between the upper and lower brasses; when the wear has been excessive these distance pieces can be planed down in a shaper very quickly. However, that is seldom necessary, as liners, or shims, consisting of varying thicknesses of sheet brass, are also fitted between the distance pieces and the brasses. By removing one of the thinnest liners a very small lost motion can be taken up and the tendency of the bearing to pound prevented. Of course, it is necessary to have some slight clearance to all bearings, else it would be difficult to distribute the oil over the rubbing surfaces. A good rule to remember for the amount of the clearance is that for every inch of diameter of a bearing there should be two one-thousandths of an inch of space. Thus for a 12-inch crankpin the clearance should be $12 \times .002 = .024$ inch. This corresponds practically to No. 24 B. W. G., which is a safe clearance space. Some engineers would set them up tighter than that, but when they do there is always a good

chance for them to heat. By the same rule a 6-inch diameter crosshead pin should have .013 inch clearance, which corresponds to No. 30 B. W. G."

"What's that mean, chief?" asked Pierce.

"B. W. G. means 'Birmingham Wire Gage.' Wire, you know, is made of a great many different diameters, and instead of expressing them as so many thousandths of an inch, it is much simpler to say No. 1, 7 or 27, or whatever it happens to be. Birmingham in England is one of the leading wire manufacturing communities, so the gage most generally used is the one which was adopted at that place many years ago.

"In adjusting a bearing, as, for example, the main bearings of the engine, the cap or top part should be removed by means of a chain hoist, and the white metal and oil grooves examined. If it is found that the brass does not bear well on the shaft journal it must be scraped down to a good fit. To do this properly the journal should be smeared over with a thin coating of red lead and oil and the cap put back in place. Where the white metal of the brass touches the shaft there will be red spots. These spots should all be carefully scraped down and the cap again tried as before. After this is repeated several times, the brass should be found to bear on the journal quite uniformly. Always remember that the principal bearing should be in the center of the brass. The outside edges should not touch at all, for if they bear on the journal when it is cold it will be found when the temperature of the bearing rises to a working heat there will be a tendency for the edges to squeeze in on the shaft; or nip, as it is termed, which will cause the bearing to become overheated. It is also necessary to fit them in this way to provide for wear, the heaviest of which is naturally in the center of the brass. After the bearing is found to be satisfactory, so far as its surface is concerned, the oil grooves should be carefully cleaned out, and

enlarged where necessary, as it is of vital importance to have the grooves amply large and so placed that a uniform distribution of the oil will take place.

"For final adjustments three strips of lead wire about 1/16 inch in diameter should be laid across each journal, one at each end and one in the middle. The cap should then be replaced, and the main bearing nuts set down as tightly as possible by means of a box-wrench and a sledge. The position of the nut in reference to the end of the bolt should be marked with a scriber, so that you will know how tight to set up on the nuts after the cap has again been taken off and the three pieces of lead wire removed. The leads, as they are called, should be measured by means of the wire gage, to see that they are of about the thickness necessary for the desired amount of clearance. A more accurate method for determining the amount of clearance from the leads is by means of the micrometer."

"Mike who?" interrupted O'Rourke.

"Don't let that word bother you, as the instrument is not an Irish invention, even if its first name is Mike," rejoined McAndrew. "It is more than likely it was invented by a German; but at any rate it is a very useful measuring machine, by means of which, through the medium of an accurately cut screw head and a graduated sleeve, thicknesses of one-thousandth of an inch, and even of one ten-thousandth inch can be readily measured. When you get to be engineers you will find it very useful to save these leads, or spaghetti, as O'Rourke calls them, for future reference. A convenient way to do it is to get a large brown-paper book, a scrapbook will do, and cut slits in the pages through which the leads can be held in place. Mark under each set of three leads the name of the bearing from which they were taken, the date, and opposite several points in their length jot down the thicknesses in thousandths of an inch.

"Even if a crankpin has been adjusted to your satisfaction by means of leads, it is always a wise precaution to put the end of a pinch bar in between the end of the brass and the crank-web, and if it does not move with a 'chug' after a quick yank on the other end of the bar, the brasses are probably too tight, and should be slacked up slightly until they can be moved in that manner.

"When eccentric straps become noisy, they should be taken apart and a small shim removed; but they should never be set up so tight that they cannot be moved all around by hand after the bearing surfaces have been oiled.

"Journals connected with the valve gear do not need adjusting very often, but when they do it is a comparatively simple matter, especially if they are fitted with strap, gib and key connections, as many of them are. When first constructed it is usual to leave from 1/16 inch to ⅛ inch clearance between the two brasses, so to adjust them afterwards it is only necessary to drive the taper key in a little further, always being sure to set up tightly on the set screw.

"Many small pin bearings where the wear is trifling are fitted with solid bushings of brass. When they become badly worn the bushings should be renewed.

"The making of new joints and packing small stuffing-boxes should be attended to while the vessel is in port, as there is nothing that annoys an engineer more while the vessel is underway than to have one of these blow out. It is a strange fatality, if I might call it that, that joints and stuffing-boxes always give way at the most inopportune times. A joint will run along perfectly tight while the ship is in a cold climate, but just as soon as she gets down South, and on some particularly hot day, 'bang!' out blows the gasket, and fills an already hot engine room full of steam and vapor.

"Then, too, it is generally the joint which is hardest to get at which lets go, while some joint that is easily remade will

run along as tight as a bottle for months at a time. The engineer who is onto his job will have all suspicious joints remade while the vessel is tied up to the wharf and there is time to do the job properly.

"The making of joints and packing of stuffing-boxes is something you will have to learn from actual experience. The various materials from which gaskets are made are as numerous as the first man up San Juan Hill, and some of them just about as reliable. As a rule, you should use only rubber gaskets for joints in water pipes. For steam joints various fibrous materials, asbestos woven with wire and usudurian are the best and last longest. In making steam joints you must be exceedingly careful to see that all the old material is scraped from both flanges, and that the flanges themselves are parallel. The holes in the gasket should be cleanly cut, and before it is slipped in place the packing should be smeared over on both sides with black lead and tallow or cylinder oil. Set up on the bolts just as tightly as possible, but not so hard as to twist some of them off, as is done occasionally by muscular young men like O'Rourke."

"Honest Injun, chief, that wasn't me that twisted that stud off the feed pump this morning. I won't say just who it was, but I think he can speak German," protested O'Rourke.

"Oho! so one of you is guilty of that very same thing only this morning, eh? Well, whichever one of you highbrows it was will have the pleasure of putting in a new stud while you are resting yourselves off watch to-morrow.

"As I was saying," resumed McAndrew, "the bolts on a new joint should be set up as tightly as possible, and then after steam has been on the pipe for an hour or so, they should be followed up, as the saying is, as the heating of the gasket usually allows a little more tightening.

"In packing stuffing-boxes, the turns of packing should be put in so that the joints do not come opposite one another,

and this packing should also be rubbed down with black lead and tallow."

"Why do you do that, chief?" asked Nelson.

"It isn't that it does any particular good in keeping the stuffing-box tight, but it makes it much easier to remove the packing when it is worn out and again has to be repacked. In marine engineering, no matter what you do in the way of construction or repairs, you must provide for all manner of things which may happen in the future. You don't want to be caught like the man who built a boat having a 6-foot beam in a cellar with only a 3-foot door to get it out of and didn't notice the difference until the boat was finished.

"Certain parts of marine machinery need to be inspected to see that everything is in good condition. I don't believe, as some engineers apparently do, in taking an engine or an auxiliary apart to see what makes it work so well, but at regular periods, say every three or four months, the cylinder heads should be lifted to see that none of the follower bolts is cracked or has become loose. Water ends of air pumps, feed pumps and bilge pumps should be examined quite frequently to see that the valves have not become too much worn and the springs are not broken and are in their proper places. This is particularly necessary if rubber valves are used. The main condenser should be watched closely to see that no leaks have developed in the tubes. This is generally indicated by the water getting too high in the gage glasses on the boilers, as salt water will leak through the tubes to the fresh water side of the condenser and mix in with the feed water, causing a surplus. If you have reason to suspect that any of the tubes are leaking the condenser should be filled with water, the water chest at each end removed, and the ends of all the tubes examined carefully to see if any water is running out. If it does, that indicates that the tube is leaking and it should be removed at once. If there are spare tubes on hand fit one

of them in its place or else plug up the holes in the tube sheets.

"After several months of use, condenser tubes become covered with grease from the exhaust steam and fall off in their efficiency of transmitting the heat from the exhaust steam to the circulating water. This is generally indicated by the vacuum falling below its usual height, and the condenser should be boiled out with a strong solution of soda and water heated by means of a jet of steam.

"There are, of course, many other jobs to be attended to while a vessel is in port; in fact, the duties of an engineer while the vessel is tied up remind me of the tribulations of a 12-year-old playmate of mine when I was a youngster. He would get home from school about 4 o'clock in the afternoon, and upon reporting to his fond stepmother would every day be saluted about as follows: 'Now, Lewis, you hurry up and get ten or twelve baskets of chips from the shipyard; run up to the grocery store for me; hoe five rows of potatoes; chop the kindling for the morning; get six pails of water and then you can play the rest of the time before supper.'

"After performing all the numerous chores I have told you about which have to be done in port the average engineer who follows the sea can play the rest of the time; but I am afraid that it is mostly after supper that he finds the opportunity."

CHAPTER XX

Examination Questions and Answers

Since the last lecture to his class McAndrew had been so busy with his regular duties that nearly a month had elapsed before another opportunity offered to give the boys in the Floating School further instruction. In the meantime the four young men had continued their studies, using such text-books as they had on hand for the purpose. It seems that Pierce, who was somewhat more ambitious than his shipmates, had, at about the time that the Chief commenced their instruction, enlisted as a student in one of the large correspondence schools and taken up its course in marine engineering. The text-books furnished with the course were very comprehensive, and Pierce had kindly loaned them to his fellow students, so that all had profited by studying them.

McAndrew commenced his remarks by saying, "We have now covered, in a somewhat brief manner, to be sure, nearly all the principal subjects necessary for an elementary understanding of marine engineering. It is now up to you to put in practice some of the things I have told you. To get your 'tickets' as assistant engineers is, of course, your ambition. The best way to prepare for your examination for a license is to work out some of the questions which have been asked by the steamboat inspectors. The existing laws in the United States concerning licenses are somewhat vague in regard to examinations, and I will quote you the following extracts from the statutes, which will be of interest to you:

"'No person shall receive an original license as engineer or assistant engineer who has not served at least three years in the engineer's department of a steam vessel. * * *

"'Any person who has served three years as apprentice to the machinist trade in a marine, stationary or locomotive engine works, and any person who has served for a period of not less than three years as a locomotive or stationary engineer, or any person graduated as a mechanical engineer from a duly recognized school of technology, may be licensed to serve as an engineer of steam vessels after having had not less than one year's experience in the engine department of steam vessels, a portion of which experience must have been obtained within the three years preceding his application, which fact must be verified by the certificate in writing of the licensed engineer or master under whom the applicant has served, said certificate to be filed with the application of the candidate; and no person shall receive license as above, except for special license, who is not able to determine the weight necessary to be placed on the lever of a safety valve (the diameter of valve, length of lever, distance from center of valve to fulcrum, weight of lever, and weight of valve and stem being known) to withstand any given pressure of steam in a boiler, or who is not able to figure and determine the strain brought on the braces of a boiler with a given pressure of steam, the position and distance apart of braces being known, such knowledge to be determined by an examination in writing, and the report of examination filed with the application in the office of the local inspectors, and no engineer or assistant engineer now holding a license shall have the grade of the same raised without possessing the above qualifications. No original license shall be granted any engineer or assistant engineer who cannot read and write and does not understand the plain rules of arithmetic.'

"So far as the letter of the law is concerned it would seem

to be very easy for you to get a license, providing you can solve the two problems called for in the above qualification. But do not fool yourselves by thinking that you can get away with a ticket so easily; while the law on the subject is very old and not brought up to date, you will find that the examiners are very much alive to present conditions. While the law requires satisfactory answers to only those two questions, it does not prohibit further questioning by the inspectors, and if you ever pass your examinations you will find that you must be pretty well posted in about every subject connected with the business."

"Chief," inquired O'Rourke, "I see that you can get a ticket inside of a year if you are a graduate—how about graduates from our school?"

"I am afraid," replied McAndrew, "that our little school here would not score very heavily as a 'recognized school of technology'; but do not be alarmed about that. Where there is one licensed marine engineer who is graduated from a 'recognized school of technology' there are at least forty-nine who have graduated from the College of Practical Experience and Self-Help. This little Floating School of ours is simply a branch of that college.

"You will notice that the law requires that every candidate must understand the plain rules of arithmetic. I know that you all understand these rules, but I am not so sure that you all understand the plain rules of mensuration, or the measurements of area and volume. No one can pass the examination who does not understand these rules, so I will devote a few moments to explaining them to you.

Measurement of Areas and Volumes

"To find the area of any plain rectangular figure, that is, one having four square corners, you multiply the length by

the breadth. Thus the side of a rectangular tank 8 feet long and 4 feet wide will contain $8 \times 4 = 32$ square feet.

"To find the volume of a rectangular tank we must multiply the length, breadth and depth together. Thus if the above tank is 4 feet in depth it will contain $8 \times 4 \times 4 = 128$ cubic feet.

"A circle is defined as a figure every point of whose circumference or boundary is equally distant from a point within called the center. You are familiar with how it is drawn with a pair of compasses. The diameter of a circle is the length of a line drawn across it and through its center. To find the length of the circumference, or distance around the circle, we multiply the diameter by the figures 3.1416. Thus if the diameter of a barrel is 2 feet, the circumference will be 2×3.1416, or 6.2832 feet.

"You will very often be required to find the area of a circle; the way to do it is to square the diameter; that is, multiply it by itself, and then multiply the quotient by the figures .7854. If you are told that a high-pressure cylinder is 30 inches in diameter, to find its area you first multiply 30×30, and get 900. Then $900 \times .7854 = 706.86$ square inches, the area.

"You must always remember those two 'constants,' as they are termed, 3.1416 for the circumference and .7854 for the area of a circle, as you will often have use for them when you do not have time to hunt them up in the text-books."

"I can remember them," said O'Rourke. "It's just as easy as remembering 4-11-44."

"Yes, and much more useful," said the instructor.

"It is also quite important for you to know how to find the volume and area of a cylinder. For example, if you are going to cover a tank with asbestos, you would want to know how to find the total area. A cylinder, you know, is a figure which if cut across perpendicular to its axis at any point

beteween the top and bottom will be circular in section. Hence if we have a cylindrical tank 5 feet in diameter and 10 feet high, and wanted to know how much material was needed to cover it all over, we would first find the circumference of a circle 5 feet in diameter, which is $5 \times 3.1416 = 15.708$ feet. Multiply this by the height, 10 feet, and we have $10 \times 15.708 = 157.08$ square feet to cover all around the sides.

"How would you find the amount of covering for the ends, O'Rourke?"

"Multiply her by .7854," replied the young man.

"Multiply what?"

"Why, the 5 feet diameter, of course," confidently said O'Rourke.

"There's where you're wrong, as usual. I told you that in order to find the area of a circle you must square the diameter. So we have $5 \times 5 = 25$ and $25 \times .7854 = 19.635$ square feet as the area of one end. But there are two ends, so we must allow for twice that, or 39.27 square feet. This added to 157.08 gives us 196.35 square feet as the total surface of the tank.

"It is of equal importance for you to be able to find the volume of a cylinder, or how much it will hold if it is hollow, or how large it is if solid. For example, we want to know how many gallons of oil or water a tank like the above will hold. To do this we must first find the area of the circle, which from the above we know to be 19.635 square feet, and as it is simpler to calculate it in inches we multiply this number by 144, or $19.635 \times 144 = 2827.4$ square inches. Right here I want to warn you against a mistake that so many beginners fall into; that is, of multiplying feet by inches. Remember, feet must always be multiplied by feet and inches by inches, or your answer will be wrong. Hence the height or depth of this tank being 10 feet, we must use

10 × 12, or 120 inches, as the multiplier. Then we have 2827.4 × 120 = 339,288 cubic inches as the volume of the tank. There are 231 cubic inches in a gallon, so we divide the total number of cubic inches in the tank, 339,288 by 231, and we find in even numbers that the tank will contain 1,469 gallons.

"There are not many spherical surfaces around marine machinery, but it might be useful at some time for you to know how to find the volume and surface of a sphere or ball. This is defined as a solid bounded by a curved surface, every point of which is equally distant from a point within known as the center. Any line through the center and cutting the surface is the diameter. We will suppose that we have a ball float in the feed tank 12 inches in diameter, and want to know how much sheet copper it will take to make such a float. The rule is to square the diameter and multiply by our old friend 3.1416. Thus 12 × 12 = 144 and 144 × 3.1416 = 452.39 square inches as the surface of the ball. Now if we had a cast iron ball 6 inches in diameter hanging on a safety valve lever, and wanted to know its weight, we would first find its volume in cubic inches. To do this the rule is to cube the diameter; that is, multiply it by itself twice, and multiply that product by .5236. Thus in this case it would be 6 × 6 × 6 = 216, and 216 × .5236 = 113.1 cubic inches in the ball. Knowing that cast iron weighs .26 pound to the cubic inch we multiply 113.1 by .26, and find that the ball weighs 29.41 pounds."

"Chief, could you use that rule to find the weight of a highball?" inquired O'Rourke.

"From all I can hear of the subject highballs haven't much weight, as their general tendency is to make you light-headed," suggested McAndrew.

Safety Valve Problems

"Now we are ready for the all-important safety valve problem, and I am particularly anxious to have you understand the principle upon which it is worked, rather than to learn some particular example, as is too often the case with beginners. When you come up for examination you will find that the conditions given you will be entirely different from any problem you may have worked out. The following is an outline sketch, which will enable you to follow out the principle involved.

"In Fig. 37, *O* represents the fulcrum, or point where the lever is hinged; *V* represents the valve; *N* the center of

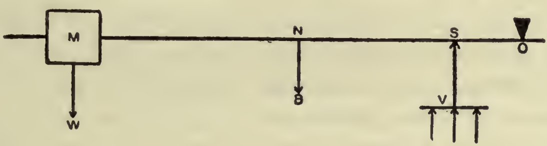

FIG. 37.—SAFTETY VALVE PROBLEM

gravity of the lever; that is the point where, if the lever should be picked up in your hand, it would exactly balance and remain in a horizontal position. *M* represents the point where the weight *W* is located on the lever. The forces acting on the lever at *M* and *N* have a tendency to make it fall or rotate in a direction opposite to the hands of a watch. The weight of the valve and stem at *S* also has that tendency. The only upward force, or the only force tending to make the lever turn in the same direction as the hands of a watch, is the pressure of the steam on the valve *V*, operating on the lever at the point *S*. Now, safety valve levers are not supposed to be rotating in either direction, but to remain in equilibrium, hence the downward forces must be such as to balance the upward force, and the only force that can be

adjusted to bring them all in equilibrium is that of the weight *W*. This can be done either by varying the weight itself or by moving it out or in from the fulcrum *O*.

"The tendency to cause the lever to rotate about the fulcrum, with a ball of a given weight, varies with the distance the ball is from the fulcrum exactly as the principle of the levers, which I have explained to you before. To measure this tendency you multiply the weight by the distance from the fulcrum, and the product is known as the moment. Thus a weight of 1 pound, placed 4 feet from the fulcrum, would have a moment of 4 foot-pounds to cause rotation. Similarly, a weight of 4 pounds placed only 1 foot from the fulcrum would have the same moment of 4 foot-pounds. If the distances were given in inches we would speak of the moments in so many inch-pounds.

"To illustrate these principles, suppose in Fig. 37 we were given the following quantities:

Distance *OS* from fulcrum to center of valve 6 inches.
Weight of valve and stem 8 pounds.
Diameter of the safety valve 3 inches.
Steam pressure 50 pounds.
Weight of lever 10 pounds.
Center of gravity of lever 20 inches from fulcrum.
Distance of weight (*OM*) from fulcrum 30 inches.
Required, the size of the weight necessary to keep the valve in equilibrium when steam is at 50 pounds pressure.

"The upward tendency is represented by the pressure of the steam at *S*. A valve 3 inches in diameter has an area of 7.07 square inches; this, multiplied by 50, the pressure per square inch, gives us a total upward pressure of 353.5 pounds. But this is 6 inches from the fulcrum, so the moment will be $353.5 \times 6 = 2{,}121.0$ inch-pounds.

"All the other weights exert downward forces and tend to

affect this upward pressure, so we will have the following to work against the 2,121 inch-pounds moment of the valve.

"Weight of valve and stem (8 pounds) multiplied by lever arms (6 inches) equals 48 inch-pounds.

"Weight of lever (10 pounds) multiplied by distance *ON* (20 inches) equals 200 inch-pounds.

"We do not yet know the size of the weight *W*, but we do know its distance from the fulcrum (30 inches), hence we add 48 and 200, and find the sum to be 248, and subtract it from 2,121 and find we have 1,873 inch-pounds to make the downward moments equal to the upward moments. This 1,873 is in inch-pounds, hence dividing it by 30 inches will give us 62.4 pounds as the size of the weight to maintain the balance.

"We will suppose that the weight (62.4) had been given us, and we were asked to ascertain what distance it should be located from the fulcrum in order to balance 50 pounds pressure on the valve. In this case we would have the same upward pressure from the valve, or 353.5 pounds, and the moment of 2,121.0 inch-pounds. The downward forces for the weights of the valve and stem and the lever will be represented by a total of 248 inch-pounds. As before, subtract this from 2,121 and we have 1,873 inch-pounds. Knowing the size of the weight in pounds (62.4) we divide it into 1,873, and find that the weight should be located 30 inches from the fulcrum in order to be in balance.

"Another way the problem might be given you is to find out what the steam pressure would be with all the conditions given as above. The downward pressures would be as before:

		Inch-Pounds
Valve and stem, 8 pounds $\times$ 6 inches	=	48
Lever, 10 pounds $\times$ 20 inches	=	200
Weight, 62.4 pounds $\times$ 30 inches	=	1,873
	Total.	2,121

"We know that the area of the valve is 7.07 square inches, and its lever arm, or distance from the fulcrum, is 6 inches, so we have $7.07 \times 6 = 42.42$. As there is only the one force acting upward we divide 2,121 by 42.42, and find that a pressure of 50 pounds can be carried with the weight set in the position given.

How to Figure the Stresses on Boiler Braces

"The next problem we will take up is the one required by law: 'to figure and determine the stresses brought on the braces of a boiler with a given pressure of steam, the position and distance apart of braces being known.'

"This is very simple, as it only involves multiplication. Thus if the braces are spaced 12 inches apart each way, and the steam pressure is 160 pounds per square inch, we multiply 12 by 12, and find that there are 144 square inches to be supported, and $144 \times 160 = 23{,}040$ pounds stress which is brought on one brace. Similarly, if the braces are spaced 14 inches apart horizontally and 10 inches vertically, and the steam pressure is 160 pounds per square inch, we would multiply 14 by 10, and find that there is an area of 140 square inches to be supported by one brace, and 140×160 would give us 22,400 pounds, or an even 10 tons, as the total stress on one brace.

"The inspectors, however, do not confine themselves to this simple form of the problem, and you are liable to get one like the above, with the addition that they would ask you the safe diameter of the brace. To perform this we must know the United States rules as to the safe working load per square inch of section. These rules give allowances of 6,000 pounds per square inch of section for iron; above 5 square inches sectional area if steel is used and regularly inspected an allowance of 8,000 pounds per square inch is made; braces above 1¼ inches diameter are not allowed to exceed 9,000

pounds per square inch of section if such stays are not forged or welded.

"You might get a question similar to the following: What diameter of bracing should be used to support a flat surface 12 inches by 12 inches, using steam at 200 pounds pressure? The solution would be 12 × 12 = 144, and 144 × 200 = 28,800 pounds to be supported; 28,800 ÷ 9,000 = 3.2 square inches. Looking at a table of areas we would find that a stay having a diameter of 2 1/16 inches has an area of 3.341 square inches, which is the nearest area to the one we know to be necessary. Very likely these braces would be made 2⅛ inches in diameter, as that would be the nearest commercial size obtainable.

Allowable Working Pressure on a Boiler

"Possibly you will be asked how to find what pressure will be allowable on a Scotch boiler, knowing the thickness of shell, the diameter of the boiler, tensile strength of plate, etc.

"The United States Government rule is to multiply one-sixth of the lowest tensile strength in pounds by the thickness in inches, and divide by one-half the diameter, also in inches; 20 percentum is to be added if double riveting is used for the horizontal seams, which, of course, would be used these days; in fact, the seams would probably be triple-riveted, but the rule makes no allowance for that.

"For example, if we had a boiler 15 feet in diameter, made of steel plates, the lowest tensile strength of which was 60,000 pounds per square inch, and the shell was 1½ inches in thickness, and we wanted to find what presure would be allowed by the inspectors, we would proceed as follows:

15 feet × 12 = 180 inches diameter.

One-half of 180 = 90 inches.

One-sixth of the lowest tensile strength (60,000 pounds) = 10,000 pounds.

$1\frac{1}{2}$ inches = 1.5 inches.

10,000 × 1.5 = 15,000.

15,000 ÷ 90 = 166.6 pounds.

"As double riveting allowances must be made, we add 20 percent of this and have 166.6 + 33.4 = 200 pounds pressure allowable on the boiler."

"Chief," said Pierce, "suppose we wanted to find out what thickness to make this boiler shell, and we knew the size and pressure we wanted to carry?"

"We would simply reverse the operation," replied McAndrew. "In other words, multiply the radius in inches by the pressure in pounds and divide by one-sixth the tensile strength. Thus 90 × 200 = 18,000; 18,000 ÷ 15,000 = 1.2 inches thick. But for double riveting an allowance of 20 percent additional is made, and 1.2 is only 80 percent (100 — 20) of the thickness allowance. As 80 percent is 1.2, 100 percent will be 1.5 inches, the thickness which we will have to make the boiler shell in order to withstand the pressure required and conform to the rules.

"Strange to say, all the problems required by law to be given candidates for engineers' licenses in this country relate to boilers. These laws were passed in the early days of steam navigation, and I presume that the legislators in those days thought that if a man understood boilers thoroughly he could manage somehow to run the engines. Fortunately for the good of the service the inspectors ask questions concerning nearly all parts of the steam machinery, so it is well to be prepared in a general way."

"Why can't we get some of the old examination papers?" observed Nelson.

"Just try it for yourself and see," said McAndrew. "In the first place they are not published, so it is not necessary to give any other reasons.

"I have, however, put down in my notebook a number of

the questions that were asked me on my different examinations, and I will give you the benefit of some of those I have had, and also of some of those I have obtained from other engineers. They are as follows:

Questions and Answers from Marine Engineers' Examination Papers

Q. What is the advantage of a triple-expansion engine over a compound; how is the power divided; how can you tell when the power is equally divided?

A. Greater economy, due to a greater degree of expansion of the steam; the power should be divided as nearly equally as possible between the three cylinders; the only way to ascertain whether the division is equal or not is to take a set of cards from each cylinder and calculate the horsepower which each develops.

Q. What are the principal types of condensers?

A. Jet and surface.

Q. What are the necessary appliances for operating a surface condenser?

A. The circulating pumps for forcing the cooling water through the tubes, and the air pump for pumping out the condensed water and the vapor from the interior of the condenser.

Q. How would you ascertain if a condenser was leaking salt water?

A. By taking off the water chest at each end and filling the condenser with fresh water. If any water runs out through the ends of the tubes there are leaks in the tubes, which, when the condenser is in operation, would admit salt water to the condenser.

Q. How many sets of valves are there in an air pump; which set could be dispensed with and the pump continue to work?

A. The valves are known as foot valves, bucket valves and discharge valves. The pump could run without foot valves, but it works better with them.

Q. What is a vacuum?

A. A vacuum means absence of air.

Q. What is steam?

A. Steam is a thin, invisible, elastic vapor formed by the application of heat to water.

Q. Is it possible to get a perfect vacuum?

A. It is not.

Q. If a vacuum gage shows 24 inches, how many pounds pressure does that indicate?

A. About 12 pounds.

Q. Suppose the steam gage shows 60 pounds and the vacuum gage 24 inches, what would be the pressure in pounds per square inch on the piston?

A. One-half of 24 inches means a pressure of 12 pounds, so the pressure per square inch on the piston would be $60 + 12 = 72$ pounds.

Q. What is the duty of a condenser?

A. A condenser serves the purpose of condensing or turning the exhaust steam back into its original state as water; in this operation a vacuum is formed which increases the power of the engine by carrying out the expansion of the steam to nearly its limit.

Q. How does a leaky condenser affect a boiler?

A. It allows salt water to be fed to the boiler, and if the leak is extensive it will cause too great a quantity of water to accumulate in the boiler, so that the boiler will have to be blown down at intervals.

Q. Describe the course of steam from the boiler to a triple-expansion engine, naming the valves and pipes, etc., it passes through until in the form of water it reaches the feed tank?

A. The steam after being formed in the boiler first passes

through the dry-pipe, the object of which is to keep the water out of the steam. It then passes through the main stop valve on the boiler into the main steam pipe. In the main steam pipe is sometimes fitted a separator which removes the water from the steam. Passing through the throttle valve it enters the high-pressure steam chest, thence through the high-pressure valve into the high-pressure cylinder; after a certain degree of expansion in that cylinder it is exhausted into the first receiver, and passing through the intermediate valve it enters the intermediate cylinder, where another degree of expansion ensues. It is exhausted from the intermediate cylinder into the second receiver, and thence through the low-pressure valve into the low-pressure cylinder, where it is expanded to its final stage and then is exhausted into the condenser. There it is transformed into water by coming in contact with the surface of the cold tubes. This water is pumped out of the bottom of the condenser by means of the air pump, and is discharged into the feed tank, whence it is again pumped into the boilers by means of the feed pump.

Q. Where should the throw of the eccentric be placed in relation to the crank of a slide valve engine?

A. It should be set ahead of the crank where the steam is taken on the outside of the valve.

Q. How would you set an eccentric on a new shaft to have the valve properly set?

A. Ninety degrees ahead of the crank, plus the amount of the lap, plus the amount of the lead. Before setting the eccentric you should lock it with a set screw, and then by turning the engine around one revolution see that the lead is correct for both ends. After it is found to be in the correct position then mark and cut the keyway in the shaft.

Q. What is meant by lap?

A. The amount a slide valve overlaps the steam port, when

it is in mid-position, if it is on the steam side. On the exhaust side it is the amount it overlaps the exhaust side. The former is used for regulating the cut-off and the latter to provide compression at each end of the stroke.

Q. What is meant by lead?

A. By lead is meant the amount the valve is open when the piston is at the end of its stroke. Lead is given to admit steam before the piston reaches the end of the stroke, and to start it off promptly on the new stroke.

Q. Can steam be cut off equally in the two ends of a cylinder when using a lap valve?

A. No, it cannot, for the reason that the crank is not horizontal when the piston is at half stroke, but a little above the center, due to the angularity of the connecting rod. When the crank is horizontal the piston is a little below the center of its stroke, therefore the steam follows further on the top.

Q. Is the lead increased or decreased by shifting the link to mid-position?

A. If you have "open" rods the lead will increase as we run in the links, and we shorten the point of cut-off. If the rods are crossed the opposite is the case.

Q. What are the practical limits of cutting off with a slide valve?

A. It is not practicable to cut off very short with a lap valve, on account of the excessive lap necessary and the increased travel of the valve. Generally speaking, it is inadvisable to cut off at less than 5/8 the stroke, nor more than 7/8.

Q. What is the difference in the throw of an eccentric of a double-ported valve from that necessary for a single-ported valve?

A. Double-ported valves are used to reduce the travel of a valve by giving a double admission at each end, hence the travel is only one-half that of a single-ported valve.

Q. Find the area of opening in a boiler shell for a duplex safety valve, each valve being $3\frac{1}{2}$ inches diameter.

A. $3.5 \times 3.5 = 12.25$, this multiplied by $.7854 = 9.62$ as the area of one valve; $9.62 \times 2 = 19.24$ as the area of the hole in the boiler. The diameter corresponding to that area is practically 5 inches.

Q. What is meant by foaming or priming? How do you explain the cause?

A. "Foaming" is the violent boiling or ebullition of the water in the boiler, the water level rises and falls rapidly, and water gets mixed with the steam and is carried to the engine; this latter action is known as "priming." Foaming is liable to occur when the boiler is dirty; when the boiler is forced to a great extent; when changing from salt to fresh feed; when too much soda is used in the boiler, or if the boiler does not have sufficient steam space.

Q. How would you check "foaming"?

A. Slow down the engine; put on a strong feed; pump and blow if necessary.

Q. What precautions are necessary when the boiler is priming?

A. Open all cylinder and valve chest drains, and if necessary slow down the engine.

Q. What are the bad effects of oil or grease getting into the boilers?

A. The oil forms a scum on the surface of the water in the boiler, and gradually collects together with particles of salt scales, sulphate of lime, etc., and will finally settle on the tubes or on the furnace crowns. Being a very poor conductor of heat it is liable to cause the metal to become overheated, with consequent collapse or bulging of the furnaces. The oil will also become decomposed, form acids and expedite electrolytic action, with its consequent pitting of the steel plates and tubes.

Q. What density would you carry the water in the boiler, using a high-pressure of steam, such as 180 pounds?

A. With steam at that pressure allow the density to rise as high as 4 or 4½ thirty-seconds before blowing, as with high temperature if we keep blowing to hold the density low, we increase the scale as the calcium sulphate in the sea water deposits at the comparatively low temperature of 290 degrees F.

Q. How would you determine the density of boiler water if the salinometer was out of order?

A. By means of noting the boiling point. Fresh water boils at 212 degrees F. under atmospheric pressure only. Ordinary sea water boils at 213.2 degrees F. At a density of 2 thirty-seconds it boils at 214.2 degrees F., and so on.

Q. How high should the water be carried over the tops of combustion chambers?

A. Not less than 6 inches.

Q. Describe a fusible plug. Where are they placed in a boiler? and for what purpose? What materials are used in their construction?

A. A fusible plug is usually made of brass, filled with Banca tin. They are to relieve the pressure in case of low water in the boiler, the theory being that the tin will melt out when there is no water over it, and allow the steam to blow through the hole thus formed. In boilers having combustion chambers they must be placed in the top, or the highest heating surface. In flue boilers one must be placed in each flue and one in the shell of the boiler from the inside just below the fire line, and not less than 4 feet from the forward end of the boiler.

Q. Where would you use a soft patch on a boiler, and how should it be applied?

A. A soft patch should be used over a weak spot on the boiler, or over a part of a joint where the rivets are corroded away and leaking. It should never be used where it

will come in contact with the fire or flames. It is usual to make them of 3/16-inch or ¼-inch plate, and of a size sufficient to overlap all portions of the weak spot to be patched. A templet of lead should be made for the patch. The patch itself should be made to correspond to the templet; it should be lipped around its edges, so as to hold the putty of red lead and iron filings. Each bolt should be fitted with washers and grommets of asbestos thread rubbed down with white lead. Bake the patch with heated irons and set up as tightly on the bolts as possible.

Q. Where on a boiler would you use a hard patch, and how should it be applied?

A. A hard patch is used for a permanent job, and can be fitted over a hole or defective part of the boiler, even if it does come in contact with the fire. The defective part should be cut out, a templet made large enough to allow for a riveted joint all around the hole. The holes should be drilled from the templet, and when all is ready drive the rivets and calk the edges all around the same as in regular boiler construction.

Q. Upon what does the strength of a cylindrical boiler depend?

A. Upon the thicknes of the shell.

Q. Why are two safety valves used instead of one?

A. The combined area of the two valves must be equal to the area of one valve, as required by the rules of the Steamboat Inspection Service. When two valves are used there is less likelihood of both getting out of order than would be the case if only one is used.

Q. What should be the angle of the seat of safety valves?

A. The seats should have an angle of inclination of 45 degrees to the center line of their axes.

Q. What determines the size of safety valves of different kinds?

A. Lever safety valves must have an area of not less than 1 square inch to 2 square feet of the grate surface. Spring loaded safety valves must have an area of not less than 1 square inch for each 3 square feet of grate surface, except for watertube boilers carrying a steam pressure exceeding 175 pounds per square inch, when they are required to have an area of not less than 1 square inch for each 6 square feet of grate surface.

Q. Name all the valves on a boiler, stating the most important one and where it is placed.

A. The valves on a marine boiler are the safety valve, main stop valve, auxiliary stop valve, main feed check valve, auxiliary feed check valve, surface blow valve, bottom blow valve, drain valve and sometimes a sentinel valve.

The most important one is the safety valve, which is placed on the shell at the highest part of the boiler.

Q. What would be the result if both feed valves were shut on a boiler and the engine was in motion at full speed?

A. The water in the boiler would be gradually used up, and if not replenished the boiler would explode.

Q. Does the water in the glass always show the true level in the boiler?

A. No, it does not. Occasionally the pipes leading to the gage glass may become choked up with hardened oil, or the valves may not be opened. These should be frequently tried to see that they are kept open.

Q. A ship has six double-ended boilers with six furnaces, each of which is 6 feet 6 inches long by 3 feet 3 inches in diameter, and when the ship is making 15 knots there is 15 pounds of coal burned per square foot of grate area per hour. How many tons of coal would be required for a voyage of 3,000 miles, and how many tons would be burned each day?

A. As each furnace is $6\frac{1}{2}$ feet long and $3\frac{1}{4}$ feet in diameter, there would be $6\frac{1}{2} \times 3\frac{1}{4} = 21\frac{1}{8}$ square feet in each

furnace; $21\frac{1}{8} \times 6 = 126\frac{3}{4}$ square feet of grate surface in each boiler; $126\frac{3}{4} \times 6 = 760\frac{1}{2}$ square feet of grate surface in all the boilers; $760\frac{1}{2} \times 15 = 11,407\frac{1}{2}$ pounds, or 5.09 tons of coal burned per hour; $3,000 \div 15 = 200$ hours' time to make the voyage of 3,000 miles; $5.09 \times 200 = 1,018$ tons to make the voyage of 3,000 miles; $5.09 \times 24 = 122.16$ tons burned each day.

Q. If you were in charge of a modern triple-expansion engine, and the intermediate connecting rod broke beyond repair, what would you do?

A. Disconnect the rod at both ends; take out the intermediate valve, so as to allow the steam to pass from the high-pressure exhaust direct to the low-pressure valve chest and proceed on the voyage, using only the high and low-pressure cylinders.

Q. How long would you run a boiler if you had used only fresh water as feed before cleaning it?

A. About 700 steaming hours with the main engine in use would be about the safe limit before opening the boiler to clean it, as it will be found at the end of that time that the zincs will need renewing.

Q. If the high-pressure valve stem broke beyond repair what would you do?

A. Take out the high-pressure valve and let the live steam from the boilers blow directly through to the intermediate valve chest, and run the engine compound with the intermediate and low-pressure cylinders.

Q. How many gallons of water is pumped per hour by a single-acting plunger pump, whose diameter is 6 inches, stroke 10 inches, and making 60 strokes per minute?

A. The area corresponding to a diameter of 6 inches is 28.27 square inches. This is found by multiplying $6 \times 6 = 36 \times .7854 = 28.27$ square inches. Now 28.27×10 inches $= 282.7$ cubic inches per stroke; $282.7 \times 60 = 16,962$ cubic

inches per hour; 16,962 ÷ 231 (number of cubic inches per gallon) = 73.4 gallons per minute; 73.4 × 60 = 4,404 gallons per hour.

Q. What are the principal things to look after upon taking charge of a watch?

A. See first if there is a half a glass of water in each boiler, that the fires are clean, that the ashes have been blown out, that some coal is out on the plates, that no bearings are running warm, that the feed pump is working well, and that a good vacuum is being carried.

Q. What height must a safety valve be raised or lifted to allow a free escape of steam equal to the area of the valve?

A. One-fourth the diameter; thus with a 4-inch safety valve it should be lifted 1 inch.

Q. Why are counterbores put into each end of a cylinder?

A. To allow the piston to run over the edge at each end of the stroke, so that it will not wear shoulders in the bore of the cylinder.

Q. A cylinder is 30 inches diameter, the steam pressure is 125 pounds, and 30 bolts hold the cylinder cover in place. What is the stress on each bolt?

A. The area corresponding to 30 inches diameter is 30 × 30 × .7854 = 706.86 square inches, 706.86 × 125 = 88,357.5 pounds total stress on the cylinder cover; 88,357.5 ÷ 30 = 2,945.25 pounds stress on each bolt.

Q. How should the valves be connected to a boiler?

A. They should always be bolted to the shell, never riveted or screwed.

Q. How would you find out the distance the piston and shaft had worked down?

A. It is customary to mark on the cross-head slipper and cross-head guides the position of the piston at the top of the stroke. If it has worked down from the original position the amount will be the difference between the marks on the guide

and the slipper. A tram is usually furnished with every engine showing the position of the top of the crankshaft, relative to the facing on the top of the bed-plate under the bearing caps. If the shaft is worn down, the distance can be ascertained by fitting the tram in place on the bed-plate facing and measuring the space between the tram and the top of the crankshaft.

Q. What are the principal things to look after before starting fires?

A. See that there is sufficient water in the boiler, that all valves work freely, particularly the feed check valves; that the air cock or the top gage cock is left open, to allow the air to escape, and that all man and hand-holes are set up tightly.

Q. Before turning the engine over what precautions are necessary for the engine and vessel?

A. Inform the deck officers so that they can see that sufficient lines are out to hold the vessel to the wharf, and that everything is clear around the propellers. In the engine-room see that the turning gear is disconnected; that the water service is turned on; that all bearings have been oiled; that there is nothing in the crank-pits, and that all hands are clear of the engine.

Q. When the pumps are connected to the engine what would you look after before starting?

A. See that the air pump is not filled with water, and that all valves on the discharge side of the feed pumps or bilge pumps are open.

Q. What are the causes of feed pumps working poorly?

A. Generally, bad management. Either the pumps are not getting the water from the hot well regularly or the check valves on the boilers may be closed. Possibly the valves in the water end of the pump are out of order.

"The foregoing questions which I have quoted cover about

the usual ground that is embodied in the examination given by the inspectors for your first papers. I do not mean to imply that you will get any of these particular questions when you go up for your tickets, but if you understand the principles upon which each of them is worked you ought to be able to pass any examination which they give you.

"This will conclude my course of lectures to you. I know I have not covered every subject in marine engineering, as many volumes have been written on the subject. I have endeavored to give you a good general idea of what you will have to know to be successful. You must not let up in your studies, as no man can keep up to date unless he is constantly studying. By that I do not mean that you should devote all your spare time to books, but at your ages you should give at least one hour a day of your time off watch to studying some of the many subjects connected with your business."

"Chief, can you recommend us some good books to get?" queried Pierce.

"Oh! yes, indeed I can; there are lots of good books which you can buy which will be very helpful to you. For example, there are several correspondence schools wherein for a small sum each month you can not only receive their courses of instruction, but you will get their text books into the bargain. As a rule these books are excellently gotten up and will be of great value to you.

"For a good all-around text book on marine engineering it is doubtful if you can find any better than that written by Prof. W. F. Durand. He was once a sea-going engineer himself before he settled down in a college, so he knows both the practical and the theoretical sides of the business. Many of the best books on marine engineering are by English authors, as the whole world must admit that Great Britain has produced some of the ablest of engineers, particularly those in the marine branch. When you get further along in

your business you should each buy yourself a copy of 'Reed's Engineer's Handbook.' All these books are, of course, very useful to you, but you can each write your own book on the subject."

"Gee! we're no highbrows," blurted out O'Rourke.

"You don't have to be to write the kind of book I'm going to tell you about.

"You should each get a good-sized blank book, made of serviceable paper for writing with ink and well bound. Whenever you see anything of interest in a text book or in any of the engineering papers you may read, copy it down in this notebook. If some older engineer tells you of a good method of making any particular kind of repairs, or gives you any information that you think will be valuable in the future, make copious notes of them in your book. As you grow older you will find that such a note book will become invaluable for reference, and it will increase in value to you every year that it is kept up. When you take your first examination write down all the questions you can remember, and work them out in your notebook. Even if they are not of much value to you after you have attained your license, they may help some young fellow who is coming after you later on.

"When these lectures which I have given you are published in book form, I am going to ask the publishers if they will print in the back of the book a lot of tables and useful information which every marine engineer should have handy. These will include tables of areas of circles, strengths of materials, temperature of steam at different pressures, weights of different kinds of substances with which marine engineers have to deal, etc. I will also ask them to bind with the book a few blank pages, upon which you can write down any other bits of information you may run across which will be of value to you in your business.

"This will be my last regular talk with you boys as a class

in the 'Floating School,' but I will be only too glad to help you with any of your problems whenever I have the opportunity. As it is about time for you to go on watch you had better turn to. I'll keep my eye on each one of you and see that you get a chance as soon as you can get your tickets."

"Chief," said Jim Pierce, who had been appointed spokesman of the class, "I cannot tell you how much all of us appreciate your kindness to us. Every one of us has benefited a great deal by the instruction you have given us, and we hope to show you by what we accomplish that your labors with us have not been lost. We want to ask you one parting favor before the 'Floating School' is broken up, and that is if you will do us the honor of going to dinner with your class when we reach New York."

"That's easy," laughingly replied McAndrew, "of course I will."

About ten days afterward the *Tuscarora* arrived in New York. The boys had talked over the dinner they were to have on every occasion when they came together.

O'Rourke insisted that it must be a "swell dinner," and that "no ordinary West Street restaurant chuck" would go. To this all very readily agreed, and it was decided that they would "blow themselves in a bang-up Broadway joint," as O'Rourke expressed it.

Promptly at the appointed hour the four sea toilers, arrayed in their best for the occasion, and accompanied by Chief McAndrew, sat down at a fashionable Broadway restaurant not far from Forty-second street. They were not, of course, togged out in evening clothes, as were most of the other men diners, but their clean-shaven faces, stalwart forms and generally spick appearance made them a very presentable group. O'Rourke had elected himself as master of ceremonies, but he was somewhat taken aback when the polite head waiter handed him several bills of fare, and asked if the party would

be served à la carte or table d'hote. After getting his breath he replied:

"Aw, cut out that frog-eater's chatter and give us the best chow you've got in the joint."

McAndrew came to the waiter's rescue, and told him to serve the dinners table d'hote, afterwards explaining to his hosts that that meant they would have to pay only $1.50 each for the dinner, and that they would get a very good meal for less than it would cost them on the other plan.

What the boys lacked in style they made up in robust appetites, so as each course was served it was quickly disposed of with a noticeable lack of the usual picking and faultfinding indulged in by the habitues of such places. True, there was somewhat of a mix-up in the use of a multiplicity of knives, forks and spoons placed at each plate, but each was made to serve a good purpose, even if Schmidt did try to eat his fish course with a combined fork and spoon usually reserved for the ice cream.

The menu was printed in French, which caused much speculation as to the composition of the next course, and some grave doubts as to the course under consideration at the time.

O'Rourke had looked forward with great expectation to the viand described as "pommes de terre au naturel," and could not refrain from venting his disappointment when they were served, by shouting out, "Gee! they're nothing but plain old boiled spuds with some grass on them."

When the "café demi-tasse" was served at the conclusion of the meal, he nearly precipitated a small riot by demanding in loud tones that he be given "a man's size cup of coffee."

However, the influence of the good dinner soon calmed his ruffled temper, and when the real Havanas, not Savannahs, as O'Rourke announced he had been accustomed to smoking, were lighted, all was serene at the table.

Drawing a small package from his pocket, Pierce, in a few

well-chosen and heartfelt words, presented it to McAndrew. Upon opening the package, McAndrew found, to his complete surprise, that it contained a handsome gold watch and chain. Upon the back of the watch was neatly engraved the following:

"To Chief Engineer James Donald McAndrew, with the highest esteem and gratitude of his pupils in the 'Floating School.'"

Quite overcome with this evidence of his pupils' appreciation of his efforts, McAndrew cleared his throat and said:

"Boys, what I have done for you was not with the hope of getting any such handsome reward as this, but from the interest which I take in young men who are anxious to advance themselves in their life work. Each one of you has the making of a good engineer in you, and I wish for you all every success in your efforts to advance. If my instructions serve to help you in accomplishing the first steps in your advancement I shall feel more than repaid. When you get further along, and want to try for higher grades of licenses, I shall, if you desire, and if conditions are such that we can all be together again, be only too glad to try to aid you in the same manner that I have attempted to do with the 'Floating School.'"

"We'll have to call it the 'Floating High School,'" responded O'Rourke, who was bound to have the last word.

THE END

Useful Tables for Marine Engineers

Properties of Saturated Steam.

(Condensed from Marks and Davis's Steam Tables and Diagrams, 1909, by permission of the publishers, Longmans, Green & Co.)

Vacuum, Inches of Mercury.	Absolute Pressure, Lbs. per Sq. In.	Temperature, Fahrenheit.	Total Heat above 32° F. In the Water h Heat-Units.	Total Heat above 32° F. In the Steam H Heat-Units.	Latent Heat, $L = H - h$ Heat-Units.	Volume, Cu. Ft. in 1 Lb. of Steam.	Weight of 1 Cu. Ft. Steam, Lb.	Entropy of the Water.	Entropy of Evaporation.
29.74	0.0886	32	0.00	1073.4	1073.4	3294	0.000304	0.0000	2.1832
29.67	0.1217	40	8.05	1076.9	1068.9	2438	0.000410	0.0162	2.1394
29.56	0.1780	50	18.08	1081.4	1063.3	1702	0.000587	0.0361	2.0865
29.40	0.2562	60	28.08	1085.9	1057.8	1208	0.000828	0.0555	2.0358
29.18	0.3626	70	38.06	1090.3	1052.3	871	0.001148	0.0745	1.9868
28.89	0.505	80	48.03	1094.8	1046.7	636.8	0.001570	0.0932	1.9398
28.50	0.696	90	58.00	1099.2	1041.2	469.3	0.002131	0.1114	1.8944
28.00	0.946	100	67.97	1103.6	1035.6	350.8	0.002851	0.1295	1.8505
27.88	1	101.83	69.8	1104.4	1034.6	333.0	0.00300	0.1327	1.8427
25.85	2	126.15	94.0	1115.0	1021.0	173.5	0.00576	0.1749	1.7431
23.81	3	141.52	109.4	1121.6	1012.3	118.5	0.00845	0.2008	1.6840
21.78	4	153.01	120.9	1126.5	1005.7	90.5	0.01107	0.2198	1.6416
19.74	5	162.28	130.1	1130.5	1000.3	73.33	0.01364	0.2348	1.6084
17.70	6	170.06	137.9	1133.7	995.8	61.89	0.01616	0.2471	1.5814
15.67	7	176.85	144.7	1136.5	991.8	53.56	0.01867	0.2579	1.5582
13.63	8	182.86	150.8	1139.0	988.2	47.27	0.02115	0.2673	1.5380
11.60	9	188.27	156.2	1141.1	985.0	42.36	0.02361	0.2756	1.5202
9.56	10	193.22	161.1	1143.1	982.0	38.38	0.02606	0.2832	1.5042
7.52	11	197.75	165.7	1144.9	979.2	35.10	0.02849	0.2902	1.4895
5.49	12	201.96	169.9	1146.5	976.6	32.36	0.03090	0.2967	1.4760
3.45	13	205.87	173.8	1148.0	974.2	30.03	0.03330	0.3025	1.4639
1.42	14	209.55	177.5	1149.4	971.9	28.02	0.03569	0.3081	1.4523
lbs. gage.	14.70	212	180.0	1150.4	970.4	26.79	0.03732	0.3118	1.4447
0.3	15	213.0	181.0	1150.7	969.7	26.27	0.03806	0.3133	1.4416
1.3	16	216.3	184.4	1152.0	967.6	24.79	0.04042	0.3183	1.4311
2.3	17	219.4	187.5	1153.1	965.6	23.38	0.04277	0.3229	1.4215
3.3	18	222.4	190.5	1154.2	963.7	22.16	0.04512	0.3273	1.4127
4.3	19	225.2	193.4	1155.2	961.8	21.07	0.04746	0.3315	1.4045
5.3	20	228.0	196.1	1156.2	960.0	20.08	0.04980	0.3355	1.3965
6.3	21	230.6	198.8	1157.1	958.3	19.18	0.05213	0.3393	1.3887
7.3	22	233.1	201.3	1158.0	956.7	18.37	0.05445	0.3430	1.3811
8.3	23	235.5	203.8	1158.8	955.1	17.62	0.05676	0.3465	1.3739
9.3	24	237.8	206.1	1159.6	953.5	16.93	0.05907	0.3499	1.3670
10.3	25	240.1	208.4	1160.4	952.0	16.30	0.0614	0.3532	1.3604
11.3	26	242.2	210.6	1161.2	950.6	15.72	0.0636	0.3564	1.3542
12.3	27	244.4	212.7	1161.9	949.2	15.18	0.0659	0.3594	1.3483
13.3	28	246.4	214.8	1162.6	947.8	14.67	0.0682	0.3623	1.3425
14.3	29	248.4	216.8	1163.2	946.4	14.19	0.0705	0.3652	1.3367
15.3	30	250.3	218.8	1163.9	945.1	13.74	0.0728	0.3680	1.3311
16.3	31	252.2	220.7	1164.5	943.8	13.32	0.0751	0.3707	1.3257
17.3	32	254.1	222.6	1165.1	942.5	12.93	0.0773	0.3733	1.3205
18.3	33	255.8	224.4	1165.7	941.3	12.57	0.0795	0.3759	1.3155
19.3	34	257.6	226.2	1166.3	940.1	12.22	0.0818	0.3784	1.3107
20.3	35	259.3	227.9	1166.8	938.9	11.89	0.0841	0.3808	1.3060
21.3	36	261.0	229.6	1167.3	937.7	11.58	0.0863	0.3832	1.3014
22.3	37	262.6	231.3	1167.8	936.6	11.29	0.0886	0.3855	1.2969
23.3	38	264.2	232.9	1168.4	935.5	11.01	0.0908	0.3877	1.2925
24.3	39	265.8	234.5	1168.9	934.4	10.74	0.0931	0.3899	1.2882
25.3	40	267.3	236.1	1169.4	933.3	10.49	0.0953	0.3920	1.2841
26.3	41	268.7	237.6	1169.8	932.2	10.25	0.0976	0.3941	1.2800

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Properties of Saturated Steam. *(Continued.)*

Gauge Pressure, Lbs. per Sq. In.	Absolute Pressure, Lbs. per Sq. In.	Temperature, Fahrenheit.	Total Heat above 32° F.		Latent Heat, $L = H - h$ Heat-Units.	Volume, Cu. Ft. in 1 Lb. of Steam.	Weight of 1 Cu. Ft. Steam, Lb.	Entropy of the Water.	Entropy of Evaporation.
			In the Water h Heat-Units.	In the Steam H Heat-Units.					
27.3	42	270.2	239.1	1170.3	931.2	10.02	0.0998	0.3962	1.2759
28.3	43	271.7	240.5	1170.7	930.2	9.80	0.1020	0.3982	1.2720
29.3	44	273.1	242.0	1171.2	929.2	9.59	0.1043	0.4002	1.2681
30.3	45	274.5	243.4	1171.6	928.2	9.39	0.1065	0.4021	1.2644
31.3	46	275.8	244.8	1172.0	927.2	9.20	0.1087	0.4040	1.2607
32.3	47	277.2	246.1	1172.4	926.3	9.02	0.1109	0.4059	1.2571
33.3	48	278.5	247.5	1172.8	925.3	8.84	0.1131	0.4077	1.2536
34.3	49	279.8	248.8	1173.2	924.4	8.67	0.1153	0.4095	1.2502
35.3	50	281.0	250.1	1173.6	923.5	8.51	0.1175	0.4113	1.2468
36.3	51	282.3	251.4	1174.0	922.6	8.35	0.1197	0.4130	1.2432
37.3	52	283.5	252.6	1174.3	921.7	8.20	0.1219	0.4147	1.2405
38.3	53	284.7	253.9	1174.7	920.8	8.05	0.1241	0.4164	1.2370
39.3	54	285.9	255.1	1175.0	919.9	7.91	0.1263	0.4180	1.2339
40.3	55	287.1	256.3	1175.4	919.0	7.78	0.1285	0.4196	1.2309
41.3	56	288.2	257.5	1175.7	918.2	7.65	0.1307	0.4212	1.2278
42.3	57	289.4	258.7	1176.0	917.4	7.52	0.1329	0.4227	1.2248
43.3	58	290.5	259.8	1176.4	916.5	7.40	0.1350	0.4242	1.2218
44.3	59	291.6	261.0	1176.7	915.7	7.28	0.1372	0.4257	1.2189
45.3	60	292.7	262.1	1177.0	914.9	7.17	0.1394	0.4272	1.2160
46.3	61	293.8	263.2	1177.3	914.1	7.06	0.1416	0.4287	1.2132
47.3	62	294.9	264.3	1177.6	913.3	6.95	0.1438	0.4302	1.2104
48.3	63	295.9	265.4	1177.9	912.5	6.85	0.1460	0.4316	1.2077
49.3	64	297.0	266.4	1178.2	911.8	6.75	0.1482	0.4330	1.2050
50.3	65	298.0	267.5	1178.5	911.0	6.65	0.1503	0.4344	1.2024
51.3	66	299.0	268.5	1178.8	910.2	6.56	0.1525	0.4358	1.1998
52.3	67	300.0	269.6	1179.0	909.5	6.47	0.1547	0.4371	1.1972
53.3	68	301.0	270.6	1179.3	908.7	6.38	0.1569	0.4385	1.1946
54.3	69	302.0	271.6	1179.6	908.0	6.29	0.1590	0.4398	1.1921
55.3	70	302.9	272.6	1179.8	907.2	6.20	0.1612	0.4411	1.1896
56.3	71	303.9	273.6	1180.1	906.5	6.12	0.1634	0.4424	1.1872
57.3	72	304.8	274.5	1180.4	905.8	6.04	0.1656	0.4437	1.1848
58.3	73	305.8	275.5	1180.6	905.1	5.96	0.1678	0.4449	1.1825
59.3	74	306.7	276.5	1180.9	904.4	5.89	0.1699	0.4462	1.1801
60.3	75	307.6	277.4	1181.1	903.7	5.81	0.1721	0.4474	1.1778
61.3	76	308.5	278.3	1181.4	903.0	5.74	0.1743	0.4487	1.1755
62.3	77	309.4	279.3	1181.6	902.3	5.67	0.1764	0.4499	1.1730
63.3	78	310.3	280.2	1181.8	901.7	5.60	0.1785	0.4511	1.1712
64.3	79	311.2	281.1	1182.1	901.0	5.54	0.1808	0.4523	1.1687
65.3	80	312.0	282.0	1182.3	900.3	5.47	0.1829	0.4535	1.1665
66.3	81	312.9	282.9	1182.5	899.7	5.41	0.1851	0.4546	1.1644
67.3	82	313.8	283.8	1182.8	899.0	5.34	0.1873	0.4557	1.1623
68.3	83	314.6	284.6	1183.0	898.4	5.28	0.1894	0.4568	1.1602
69.3	84	315.4	285.5	1183.2	897.7	5.22	0.1915	0.4579	1.1581
70.3	85	316.3	286.3	1183.4	897.1	5.16	0.1937	0.4590	1.1561
71.3	86	317.1	287.2	1183.6	896.4	5.10	0.1959	0.4601	1.1540
72.3	87	317.9	288.0	1183.8	895.8	5.05	0.1980	0.4612	1.1520
73.3	88	318.7	288.9	1184.0	895.2	5.00	0.2001	0.4623	1.1500
74.3	89	319.5	289.7	1184.2	894.6	4.94	0.2023	0.4633	1.1481
75.3	90	320.3	290.5	1184.4	893.9	4.89	0.2044	0.4644	1.1461
76.3	91	321.1	291.3	1184.6	893.3	4.84	0.2065	0.4654	1.1442
77.3	92	321.8	292.1	1184.8	892.7	4.79	0.2087	0.4664	1.1423
78.3	93	322.6	292.9	1185.0	892.1	4.74	0.2109	0.4674	1.1404
79.3	94	323.4	293.7	1185.2	891.5	4.69	0.2130	0.4684	1.1385
80.3	95	324.1	294.5	1185.4	890.9	4.65	0.2151	0.4694	1.1367

Properties of Saturated Steam. (*Continued.*)

Gauge Pressure, Lbs. per Sq. In.	Absolute Pressure, Lbs. per Sq. In.	Temperature, Fahrenheit.	Total Heat above 32° F. In the Water h Heat-Units.	Total Heat above 32° F. In the Steam H Heat-Units.	Latent Heat, $L = H - h$ Heat-Units.	Volume, Cu. Ft. in 1 Lb. of Steam.	Weight of 1 Cu. Ft. Steam, Lb.	Entropy of the Water.	Entropy of Evaporation.
81.3	96	324.9	295.3	1185.6	890.3	4.60	0.2172	0.4704	1.1348
82.3	97	325.6	296.1	1185.8	889.7	4.56	0.2193	0.4714	1.1330
83.3	98	326.4	296.8	1186.0	889.2	4.51	0.2215	0.4724	1.1312
84.3	99	327.1	297.6	1186.2	888.6	4.47	0.2237	0.4733	1.1295
85.3	100	327.8	298.3	1186.3	888.0	4.429	0.2258	0.4743	1.1277
87.3	102	329.3	299.8	1186.7	886.9	4.347	0.2300	0.4762	1.1242
89.3	104	330.7	301.3	1187.0	885.8	4.268	0.2343	0.4780	1.1208
91.3	106	332.0	302.7	1187.4	884.7	4.192	0.2386	0.4798	1.1174
93.3	108	333.4	304.1	1187.7	883.6	4.118	0.2429	0.4816	1.1141
95.3	110	334.8	305.5	1188.0	882.5	4.047	0.2472	0.4834	1.1108
97.3	112	336.1	306.9	1188.4	881.4	3.978	0.2514	0.4852	1.1076
99.3	114	337.4	308.3	1188.7	880.4	3.912	0.2556	0.4869	1.1045
101.3	116	338.7	309.6	1189.0	879.3	3.848	0.2599	0.4886	1.1014
103.3	118	340.0	311.0	1189.3	878.3	3.786	0.2641	0.4903	1.0984
105.3	120	341.3	312.3	1189.6	877.2	3.726	0.2683	0.4919	1.0954
107.3	122	342.5	313.6	1189.8	876.2	3.668	0.2726	0.4935	1.0924
109.3	124	343.8	314.9	1190.1	875.2	3.611	0.2769	0.4951	1.0895
111.3	126	345.0	316.2	1190.4	874.2	3.556	0.2812	0.4967	1.0865
113.3	128	346.2	317.4	1190.7	873.3	3.504	0.2854	0.4982	1.0837
115.3	130	347.4	318.6	1191.0	872.3	3.452	0.2897	0.4998	1.0809
117.3	132	348.5	319.9	1191.2	871.3	3.402	0.2939	0.5013	1.0782
119.3	134	349.7	321.1	1191.5	870.4	3.354	0.2981	0.5028	1.0755
121.3	136	350.8	322.3	1191.7	869.4	3.308	0.3023	0.5043	1.0728
123.3	138	352.0	323.4	1192.0	868.5	3.263	0.3065	0.5057	1.0702
125.3	140	353.1	324.6	1192.2	867.6	3.219	0.3107	0.5072	1.0675
127.3	142	354.2	325.8	1192.5	866.7	3.175	0.3150	0.5086	1.0649
129.3	144	355.3	326.9	1192.7	865.8	3.133	0.3192	0.5100	1.0624
131.3	146	356.3	328.0	1192.9	864.9	3.092	0.3234	0.5114	1.0599
133.3	148	357.4	329.1	1193.2	864.0	3.052	0.3276	0.5128	1.0574
135.3	150	358.5	330.2	1193.4	863.2	3.012	0.3320	0.5142	1.0550
137.3	152	359.5	331.4	1193.6	862.3	2.974	0.3362	0.5155	1.0525
139.3	154	360.5	332.4	1193.8	861.4	2.938	0.3404	0.5169	1.0501
141.3	156	361.6	333.5	1194.1	860.6	2.902	0.3446	0.5182	1.0477
143.3	158	362.6	334.6	1194.3	859.7	2.868	0.3488	0.5195	1.0454
145.3	160	363.6	335.6	1194.5	858.8	2.834	0.3529	0.5208	1.0431
147.3	162	364.6	336.7	1194.7	858.0	2.801	0.3570	0.5220	1.0409
149.3	164	365.6	337.7	1194.9	857.2	2.769	0.3612	0.5233	1.0387
151.3	166	366.5	338.7	1195.1	856.4	2.737	0.3654	0.5245	1.0365
153.3	168	367.5	339.7	1195.3	855.5	2.706	0.3696	0.5257	1.0343
155.3	170	368.5	340.7	1195.4	854.7	2.675	0.3738	0.5269	1.0321
157.3	172	369.4	341.7	1195.6	853.9	2.645	0.3780	0.5281	1.0300
159.3	174	370.4	342.7	1195.8	853.1	2.616	0.3822	0.5293	1.0278
161.3	176	371.3	343.7	1196.0	852.3	2.588	0.3864	0.5305	1.0257
163.3	178	372.2	344.7	1196.2	851.5	2.560	0.3906	0.5317	1.0235
165.3	180	373.1	345.6	1196.4	850.8	2.533	0.3948	0.5328	1.0215
167.3	182	374.0	346.6	1196.6	850.0	2.507	0.3989	0.5339	1.0195
169.3	184	374.9	347.6	1196.8	849.2	2.481	0.4031	0.5351	1.0174
171.3	186	375.8	348.5	1196.9	848.4	2.455	0.4073	0.5362	1.0154
173.3	188	376.7	349.4	1197.1	847.7	2.430	0.4115	0.5373	1.0134
175.3	190	377.6	350.4	1197.3	846.9	2.406	0.4157	0.5384	1.0114
177.3	192	378.5	351.3	1197.4	846.1	2.381	0.4199	0.5395	1.0095
179.3	194	379.3	352.2	1197.6	845.4	2.358	0.4241	0.5405	1.0076
181.3	196	380.2	353.1	1197.8	844.7	2.335	0.4283	0.5416	1.0056
183.3	198	381.0	354.0	1197.9	843.9	2.312	0.4325	0.5426	1.0038

Properties of Saturated Steam. (*Continued.*)

Gauge Pressure, Lbs. per Sq. In.	Absolute Pressure, Lbs. per Sq. In.	Temperature, Fahrenheit.	Total Heat above 32° F. In the Water h Heat-Units.	Total Heat above 32° F. In the Steam H Heat-Units.	Latent Heat, $L = H - h$ Heat-Units.	Volume, Cu. Ft. in 1 Lb. of Steam.	Weight of 1 Cu. Ft. Steam, Lb.	Entropy of the Water.	Entropy of Evaporation.
185.3	200	381.9	354.9	1198.1	843.2	2.290	0.437	0.5437	1.0019
190.3	205	384.0	357.1	1198.5	841.4	2.237	0.447	0.5463	0.9973
195.3	210	386.0	359.2	1198.8	839.6	2.187	0.457	0.5488	0.9928
200.3	215	388.0	361.4	1199.2	837.9	2.138	0.468	0.5513	0.9885
205.3	220	389.9	363.4	1199.6	836.2	2.091	0.478	0.5538	0.9841
210.3	225	391.9	365.5	1199.9	834.4	2.046	0.489	0.5562	0.9799
215.3	230	393.8	367.5	1200.2	832.8	2.004	0.499	0.5586	0.9758
220.3	235	395.6	369.4	1200.6	831.1	1.964	0.509	0.5610	0.9717
225.3	240	397.4	371.4	1200.9	829.5	1.924	0.520	0.5633	0.9676
230.3	245	399.3	373.3	1201.2	827.9	1.887	0.530	0.5655	0.9638
235.3	250	401.1	375.2	1201.5	826.3	1.850	0.541	0.5676	0.9600
245.3	260	404.5	378.9	1202.1	823.1	1.782	0.561	0.5719	0.9525
255.3	270	407.9	382.5	1202.6	820.1	1.718	0.582	0.5760	0.9454
265.3	280	411.2	386.0	1203.1	817.1	1.658	0.603	0.5800	0.9385
275.3	290	414.4	389.4	1203.6	814.2	1.602	0.624	0.5840	0.9316
285.3	300	417.5	392.7	1204.1	811.3	1.551	0.645	0.5878	0.9251
295.3	310	420.5	395.9	1204.5	808.5	1.502	0.666	0.5915	0.9187
305.3	320	423.4	399.1	1204.9	805.8	1.456	0.687	0.5951	0.9125
315.3	330	426.3	402.2	1205.3	803.1	1.413	0.708	0.5986	0.9065
325.3	340	429.1	405.3	1205.7	800.4	1.372	0.729	0.6020	0.9006
335.3	350	431.9	408.2	1206.1	797.8	1.334	0.750	0.6053	0.8949
345.3	360	434.6	411.2	1206.4	795.3	1.298	0.770	0.6085	0.8894
355.3	370	437.2	414.0	1206.8	792.8	1.264	0.791	0.6116	0.8840
365.3	380	439.8	416.8	1207.1	790.3	1.231	0.812	0.6147	0.8788
375.3	390	442.3	419.5	1207.4	787.9	1.200	0.833	0.6178	0.8737
385.3	400	444.8	422	1208	786	1.17	0.86	0.621	0.868
435.3	450	456.5	435	1209	774	1.04	0.96	0.635	0.844
485.3	500	467.3	448	1210	762	0.93	1.08	0.648	0.822
535.3	550	477.3	459	1210	751	0.83	1.20	0.659	0.801
585.3	600	486.6	469	1210	741	0.76	1.32	0.670	0.783

Available Energy in Expanding Steam. — Rankine Cycle. (J. B. Stanwood, *Power*, June 9, 1908.) — A simple formula for finding, with the aid of the steam and entropy tables, the available energy per pound of steam in B.T.U. when it is expanded adiabatically from a higher to a lower pressure is:

$$U = H - H_1 + T(N_1 - N).$$

U = available B.T.U. in 1 lb. of expanding steam; H and H_1 total heat in 1 lb. steam at the two pressures; T = absolute temperature at the lower pressure; $N - N_1$, difference of entropy of 1 lb. of steam at the two pressures.

Example. — Required the available B.T.U. in 1 lb. steam expanded from 100 lbs. to 14.7 lbs. absolute. $H = 1186.3$; $H_1 = 1150.4$; $T = 672$; $N = 1.602$; $N_1 = 1.756$. $35.9 + 103.5 = 138.4$.

Efficiency of the Cycle. — Let the steam be made from feed-water at 212°. Heat required $= 1186.3 - 180 = 1006.3$; efficiency $= 138.4 \div 1006.3 = 0.1375$.

Rankine Cycle. — This efficiency is that of the Rankine cycle, which assumes that the steam is expanded adiabatically to the lowest pressure and temperature, and that the feed-water from which the steam is made is introduced into the system at the same low temperature.

Carnot Cycle. — The Carnot ideal cycle, which assumes that all the heat entering the system enters at the highest temperature, and in which the efficiency is $(T_1 - T_2) \div T_1$, gives $(327.8 - 212) \div (327.8 + 460) = 0.1470$ and the available energy in B.T.U. $= 0.1470 \times 1006.3 = 147.9$ B.T.U.

WIRE AND SHEET-METAL GAUGES COMPARED.

Number of Gauge.	Birmingham (or Stubs' Iron) Wire Gauge.	American or Brown and Sharpe Gauge.	Roebling's and Washburn & Moen's Gauge.	Stubs' Steel Wire Gauge. (See also p. 30.)	British Imperial Standard Wire Gauge. (Legal Standard in Great Britain since March 1, 1884.)		U.S. Standard Gauge for Sheet and Plate Iron and Steel. 1893.	Number of Gauge.
	inch.	inch.	inch.	inch.	inch.	millim.	inch.	
0000000			.49		.500	12.7	.5	7/0
000000			.46		.464	11.73	.469	6/0
00000			.43		.432	10.97	.438	5/0
0000	.454	.46	.393		.4	10.16	.406	4/0
000	.425	.40964	.362		.372	9.45	.375	3/0
00	.38	.3648	.331		.348	8.84	.344	2/0
0	.34	.32486	.307		.324	8.23	.313	0
1	.3	.2893	.283	.227	.3	7.62	.281	1
2	.284	.25763	.263	.219	.276	7.01	.266	2
3	.259	.22942	.244	.212	.252	6.4	.25	3
4	.238	.20431	.225	.207	.232	5.89	.234	4
5	.22	.18194	.207	.204	.212	5.38	.219	5
6	.203	.16202	.192	.201	.192	4.88	.203	6
7	.18	.14428	.177	.199	.176	4.47	.188	7
8	.165	.12849	.162	.197	.16	4.06	.172	8
9	.148	.11443	.148	.194	.144	3.66	.156	9
10	.134	.10189	.135	.191	.128	3.25	.141	10
11	.12	.09074	.12	.188	.116	2.95	.125	11
12	.109	.08081	.105	.185	.104	2.64	.109	12
13	.095	.07196	.092	.182	.092	2.34	.094	13
14	.083	.06408	.08	.180	.08	2.03	.078	14
15	.072	.05707	.072	.178	.072	1.83	.07	15
16	.065	.05082	.063	.175	.064	1.63	.0625	16
17	.058	.04526	.054	.172	.056	1.42	.0563	17
18	.049	.0403	.047	.168	.048	1.22	.05	18
19	.042	.03589	.041	164	.04	1.02	.0438	19
20	.035	.03196	.035	.161	.036	.91	.0375	20
21	.032	.02846	.032	.157	.032	.81	.0344	21
22	.028	.02535	.028	.155	.028	.71	.0313	22
23	.025	.02257	.025	.153	.024	.61	.0281	23
24	.022	.0201	.023	.151	.022	.56	.025	24
25	.02	.0179	.02	.148	.02	.51	.0219	25
26	.018	.01594	.018	.146	.018	.46	.0188	26
27	.016	.01419	.017	.143	.0164	.42	.0172	27
28	.014	.01264	.016	.139	.0148	.38	.0156	28
29	.013	.01126	.015	.134	.0136	.35	.0141	29
30	.012	.01002	.014	.127	.0124	.31	.0125	30
31	.01	.00893	.013	.120	.0116	.29	.0109	31
32	.009	.00795	.013	.115	.0108	.27	.0101	32
33	.008	.00708	.011	.112	.01	.25	.0094	33
34	.007	.0063	.01	.110	.0092	.23	.0086	34
35	.005	.00561	.00	.108	.0084	.21	.0078	35
36	.004	.005	.009	.106	.0076	.19	.007	36
37		.00445	.0085	.103	.0068	.17	.0066	37
38		.00396	.008	.101	.006	.15	.0063	38
39		.00353	.0075	.099	.0052	.13		39
40		.00314	.007	.097	.0048	.12		40
41				.095	.0044	.11		41
42				.092	.004	.10		42
43				.088	.0036	.09		43
44				.085	.0032	.08		44
45				.081	.0028	.07		45
46				.079	.0024	.06		46
47				.077	.002	.05		47
48				.075	.0016	.04		48
49				.092	.0012	.03		49
50				.069	.001	.025		50

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SQUARES, CUBES, SQUARE ROOTS AND CUBE ROOTS OF NUMBERS FROM 0.1 TO 1600.

No.	Square.	Cube.	Sq. Root.	Cube Root.	No.	Square.	Cube.	Sq. Root.	Cube Root.
0.1	.01	.001	.3162	.4642	3.1	9.61	29.791	1.761	1.458
.15	.0225	.0034	.3873	.5313	.2	10.24	32.768	1.789	1.474
.2	.04	.008	.4472	.5848	.3	10.89	35.937	1.817	1.489
.25	.0625	.0156	.500	.6300	.4	11.56	39.304	1.844	1.504
.3	.09	.027	.5477	.6694	.5	12.25	42.875	1.871	1.518
.35	.1225	.0429	.5916	.7047	.6	12.96	46.656	1.897	1.533
.4	16	.064	.6325	.7368	.7	13.69	50.653	1.924	1.547
.45	.2025	.0911	.6708	.7663	.8	14.44	54.872	1.949	1.560
.5	.25	.125	.7071	.7937	.9	15.21	59.319	1.975	1.574
.55	.3025	.1664	.7416	.8193	4.	16.	64.	2.	1.5874
.6	.36	.216	.7746	.8434	.1	16.81	68.921	2.025	1.601
.65	.4225	.2746	.8062	.8662	.2	17.64	74.088	2.049	1.613
.7	.49	.343	.8367	.8879	.3	18.49	79.507	2.074	1.626
.75	.5625	.4219	.8660	.9086	.4	19.36	85.184	2.098	1.639
.8	.64	.512	.8944	.9283	.5	20.25	91.125	2.121	1.651
.85	.7225	.6141	.9219	.9473	.6	21.16	97.336	2.145	1.663
.9	.81	.729	.9487	.9655	.7	22.09	103.823	2.168	1.675
.95	.9025	.8574	.9747	.9830	.8	23.04	110.592	2.191	1.687
1.	1.	1.	1.	1.	.9	24.01	117.649	2.214	1.698
1.05	1.1025	1.158	1.025	1.016	5.	25.	125.	2.2361	1.7100
1.1	1.21	1.331	1.049	1.032	.1	26.01	132.651	2.258	1.721
1.15	1.3225	1.521	1.072	1.048	.2	27.04	140.608	2.280	1.732
1.2	1.44	1.728	1.095	1.063	.3	28.09	148.877	2.302	1.744
1.25	1.5625	1.953	1.118	1.077	.4	29.16	157.464	2.324	1.754
1.3	1.69	2.197	1.140	1.091	.5	30.25	166.375	2.345	1.765
1.35	1.8225	2.460	1.162	1.105	.6	31.36	175.616	2.366	1.776
1.4	1.96	2.744	1.183	1.119	.7	32.49	185.193	2.387	1.786
1.45	2.1025	3.049	1.204	1.132	.8	33.64	195.112	2.408	1.797
1.5	2.25	3.375	1.2247	1.1447	.9	34.81	205.379	2.429	1.807
1.55	2.4025	3.724	1.245	1.157	6.	36.	216.	2.4495	1.8171
1.6	2.56	4.096	1.265	1.170	.1	37.21	226.981	2.470	1.827
1.65	2.7225	4.492	1.285	1.182	.2	38.44	238.328	2.490	1.837
1.7	2.89	4.913	1.304	1.193	.3	39.69	250.047	2.510	1.847
1.75	3.0625	5.359	1.323	1.205	.4	40.96	262.144	2.530	1.857
1.8	3.24	5.832	1.342	1.216	.5	42.25	274.625	2.550	1.866
1.85	3.4225	6.332	1.360	1.228	.6	43.56	287.496	2.569	1.876
1.9	3.61	6.859	1.378	1.239	.7	44.89	300.763	2.588	1.885
1.95	3.8025	7.415	1.396	1.249	.8	46.24	314.432	2.608	1.895
2.	4.	8.	1.4142	1.2599	.9	47.61	328.509	2.627	1.904
.1	4.41	9.261	1.449	1.281	7.	49.	343.	2.6458	1.9129
.2	4.84	10.648	1.483	1.301	.1	50.41	357.911	2.665	1.922
.3	5.29	12.167	1.517	1.320	.2	51.84	373.248	2.683	1.931
.4	5.76	13.824	1.549	1.339	.3	53.29	389.017	2.702	1.940
.5	6.25	15.625	1.581	1.357	.4	54.76	405.224	2.720	1.949
.6	6.76	17.576	1.612	1.375	.5	56.25	421.875	2.739	1.957
.7	7.29	19.683	1.643	1.392	.6	57.76	438.976	2.757	1.966
.8	7.84	21.952	1.673	1.409	.7	59.29	456.533	2.775	1.975
.9	8.41	24.389	1.703	1.426	.8	60.84	474.552	2.793	1.983
3.	9.	27.	1.7321	1.4422	.9	62.41	493.039	2.811	1.992

No.	Square.	Cube.	Sq. Root.	Cube Root.	No.	Square	Cube.	Sq. Root.	Cube Root.
8.	64.	512.	2.8284	2.	45	2025	91125	6.7082	3.5569
.1	65.61	531.441	2.846	2.008	46	2116	97336	6.7823	3.5830
.2	67.24	551.368	2.864	2.017	47	2209	103823	6.8557	3.6088
.3	68.89	571.787	2.881	2.025	48	2304	110592	6.9282	3.6342
.4	70.56	592.704	2.898	2.033	49	2401	117649	7.	3.6593
.5	72.25	614.125	2.915	2.041	50	2500	125000	7.0711	3.6840
.6	73.96	636.056	2.933	2.049	51	2601	132651	7.1414	3.7084
.7	75.69	658.503	2.950	2.057	52	2704	140608	7.2111	3.7325
.8	77.44	681.472	2.966	2.065	53	2809	148877	7.2801	3.7563
.9	79.21	704.969	2.983	2.072	54	2916	157464	7.3485	3.7798
9.	81.	729.	3.	2.0801	55	3025	166375	7.4162	3.8030
.1	82.81	753.571	3.017	2.088	56	3136	175616	7.4833	3.8259
.2	84.64	778.688	3.033	2.095	57	3249	185193	7.5498	3.8485
.3	86.49	804.357	3.050	2.103	58	3364	195112	7.6158	3.8709
.4	88.36	830.584	3.066	2.110	59	3481	205379	7.6811	3.8930
.5	90.25	857.375	3.082	2.118	60	3600	216000	7.7460	3.9149
.6	92.16	884.736	3.098	2.125	61	3721	226981	7.8102	3.9365
.7	94.09	912.673	3.114	2.133	62	3844	238328	7.8740	3.9579
.8	96.04	941.192	3.130	2.140	63	3969	250047	7.9373	3.9791
.9	98.01	970.299	3.146	2.147	64	4096	262144	8.	4.
10	100	1000	3.1623	2.1544	65	4225	274625	8.0623	4.0207
11	121	1331	3.3166	2.2240	66	4356	287496	8.1240	4.0412
12	144	1728	3.4641	2.2894	67	4489	300763	8.1854	4.0615
13	169	2197	3.6056	2.3513	68	4624	314432	8.2462	4.0817
14	196	2744	3.7417	2.4101	69	4761	328509	8.3066	4.1016
15	225	3375	3.8730	2.4662	70	4900	343000	8.3666	4.1213
16	256	4096	4.	2.5198	71	5041	357911	8.4261	4.1408
17	289	4913	4.1231	2.5713	72	5184	373248	8.4853	4.1602
18	324	5832	4.2426	2.6207	73	5329	389017	8.5440	4.1793
19	361	6859	4.3589	2.6684	74	5476	405224	8.6023	4.1983
20	400	8000	4.4721	2.7144	75	5625	421875	8.6603	4.2172
21	441	9261	4.5826	2.7589	76	5776	438976	8.7178	4.2358
22	484	10648	4.6904	2.8020	77	5929	456533	8.7750	4.2543
23	529	12167	4.7958	2.8439	78	6084	474552	8.8318	4.2727
24	576	13824	4.8990	2.8845	79	6241	493039	8.8882	4.2908
25	625	15625	5.	2.9240	80	6400	512000	8.9443	4.3089
26	676	17576	5.0990	2.9625	81	6561	531441	9.	4.3267
27	729	19683	5.1962	3.	82	6724	551368	9.0554	4.3445
28	784	21952	5.2915	3.0366	83	6889	571787	9.1104	4.3621
29	841	24389	5.3852	3.0723	84	7056	592704	9,1652	4.3795
30	900	27000	5.4772	3.1072	85	7225	614125	9.2195	4.3968
31	961	29791	5.5678	3.1414	86	7396	636056	9.2736	4.4140
32	1024	32768	5.6569	3.1748	87	7569	658503	9.3276	4.4310
33	1089	35937	5.7446	3.2075	88	7744	681472	9.3808	4.4480
34	1156	39304	5.8310	3.2396	89	7921	704969	9.4340	4.4647
35	1225	42875	5.9161	3.2711	90	8100	729000	9.4868	4.4814
36	1296	46656	6.	3.3019	91	8281	753571	9.5394	4.4979
37	1369	50653	6.0828	3.3322	92	8464	778688	9.5917	4.5144
38	1444	54872	6.1644	3.3620	93	8649	804357	9.6437	4.5307
39	1521	59319	6.2450	3.3912	94	8836	830584	9.6954	4.5468
40	1600	64000	6.3246	3.4200	95	9025	857375	9.7468	4.5629
41	1681	68921	6 4031	3.4482	96	9216	884736	9.7980	4.5789
42	1764	74088	6.4807	3.4760	97	9409	912673	9.8489	4.5947
43	1849	79507	6.5574	3.5034	98	9604	941192	9.8995	4.6104
44	1936	85184	6.6332	3.5303	99	9801	970299	9.9499	4.6261

No.	Sq.	Cube.	Sq. Root.	Cube Root.	No.	Square.	Cube.	Sq. Root.	Cube Root.
100	10000	1000000	10.	4.6416	155	24025	3723875	12.4499	5.3717
101	10201	1030301	10.0499	4.6570	156	24336	3796416	12.4900	5.3832
102	10404	1061208	10.0995	4.6723	157	24649	3869893	12.5300	5.3947
103	10609	1092727	10.1489	4.6875	158	24964	3944312	12.5698	5.4061
104	10816	1124864	10.1980	4.7027	159	25281	4019679	12.6095	5.4175
105	11025	1157625	10.2470	4.7177	160	25600	4096000	12.6491	5.4288
106	11236	1191016	10.2956	4.7326	161	25921	4173281	12.6886	5.4401
107	11449	1225043	10.3441	4.7475	162	26244	4251528	12.7279	5.4514
108	11664	1259712	10.3923	4.7622	163	26569	4330747	12.7671	5.4626
109	11881	1295029	10.4403	4.7769	164	26896	4410944	12.8062	5.4737
110	12100	1331000	10.4881	4.7914	165	27225	4492125	12.8452	5.4848
111	12321	1367631	10.5357	4.8059	166	27556	4574296	12.8841	5.4959
112	12544	1404928	10.5830	4.8203	167	27889	4657463	12.9228	5.5069
113	12769	1442897	10.6301	4.8346	168	28224	4741632	12.9615	5.5178
114	12996	1481544	10.6771	4.8488	169	28561	4826809	13.0000	5.5288
115	13225	1520875	10.7238	4.8629	170	28900	4913000	13.0384	5.5397
116	13456	1560896	10.7703	4.8770	171	29241	5000211	13.0767	5.5505
117	13689	1601613	10.8167	4.8910	172	29584	5088448	13.1149	5.5613
118	13924	1643032	10.8628	4.9049	173	29929	5177717	13.1529	5.5721
119	14161	1685159	10.9087	4.9187	174	30276	5268024	13.1909	5.5828
120	14400	1728000	10.9545	4.9324	175	30625	5359375	13.2288	5.5934
121	14641	1771561	11.0000	4.9461	176	30976	5451776	13.2665	5.6041
122	14884	1815848	11.0454	4.9597	177	31329	5545233	13.3041	5.6147
123	15129	1860867	11.0905	4.9732	178	31684	5639752	13.3417	5.6252
124	15376	1906624	11.1355	4.9866	179	32041	5735339	13.3791	5.6357
125	15625	1953125	11.1803	5.0000	180	32400	5832000	13.4164	5.6462
126	15876	2000376	11.2250	5.0133	181	32761	5929741	13.4536	5.6567
127	16129	2048383	11.2694	5.0265	182	33124	6028568	13.4907	5.6671
128	16384	2097152	11.3137	5.0397	183	33489	6128487	13.5277	5.6774
129	16641	2146689	11.3578	5.0528	184	33856	6229504	13.5647	5.6877
130	16900	2197000	11.4018	5.0658	185	34225	6331625	13.6015	5.6980
131	17161	2248091	11.4455	5.0788	186	34596	6434856	13.6382	5.7083
132	17424	2299968	11.4891	5.0916	187	34969	6539203	13.6748	5.7185
133	17689	2352637	11.5326	5.1045	188	35344	6644672	13.7113	5.7287
134	17956	2406104	11.5758	5.1172	189	35721	6751269	13.7477	5.7388
135	18225	2460375	11.6190	5.1299	190	36100	6859000	13.7840	5.7489
136	18496	2515456	11.6619	5.1426	191	36481	6967871	13.8203	5.7590
137	18769	2571353	11.7047	5.1551	192	36864	7077888	13.8564	5.7690
138	19044	2628072	11.7473	5.1676	193	37249	7189057	13.8924	5.7790
139	19321	2685619	11.7898	5.1801	194	37636	7301384	13.9284	5.7890
140	19600	2744000	11.8322	5.1925	195	38025	7414875	13.9642	5.7989
141	19881	2803221	11.8743	5.2048	196	38416	7529536	14.0000	5.8088
142	20164	2863288	11.9164	5.2171	197	38809	7645373	14.0357	5.8186
143	20449	2924207	11.9583	5.2293	198	39204	7762392	14.0712	5.8285
144	20736	2985984	12.0000	5.2415	199	39601	7880599	14.1067	5.8383
145	21025	3048625	12.0416	5.2536	200	40000	8000000	14.1421	5.8480
146	21316	3112136	12.0830	5.2656	201	40401	8120601	14.1774	5.8578
147	21609	3176523	12.1244	5.2776	202	40804	8242408	14.2127	5.8675
148	21904	3241792	12.1655	5.2896	203	41209	8365427	14.2478	5.8771
149	22201	3307949	12.2066	5.3015	204	41616	8489664	14.2829	5.8868
150	22500	3375000	12.2474	5.3133	205	42025	8615125	14.3178	5.8964
151	22801	3442951	12.2882	5.3251	206	42436	8741816	14.3527	5.9059
152	23104	3511808	12.3288	5.3368	207	42849	8869743	14.3875	5.9155
153	23409	3581577	12.3693	5.3485	208	43264	8998912	14.4222	5.9250
154	23716	3652264	12.4097	5.3601	209	43681	9129329	14.4568	5.9345

No.	Sq.	Cube.	Sq. Root.	Cube Root.	No.	Square.	Cube.	Sq. Root.	Cube Root.
210	44100	9261000	14.4914	5.9439	265	70225	18609625	16.2788	6.4232
211	44521	9393931	14.5258	5.9533	266	70756	18821096	16.3095	6.4312
212	44944	9528128	14.5602	5.9627	267	71289	19034163	16.3401	6.4393
213	45369	9663597	14.5945	5.9721	268	71824	19248832	16.3707	6.4473
214	45796	9800344	14.6287	5.9814	269	72361	19465109	16.4012	6.4553
215	46225	9938375	14.6629	5.9907	270	72900	19683000	16.4317	6.4633
216	46656	10077696	14.6969	6.0000	271	73441	19902511	16.4621	6.4713
217	47089	10218313	14.7309	6.0092	272	73984	20123648	16.4924	6.4792
218	47524	10360232	14.7648	6.0185	273	74529	20346417	16.5227	6.4872
219	47961	10503459	14.7986	6.0277	274	75076	20570824	16.5529	6.4951
220	48400	10648000	14.8324	6.0368	275	75625	20796875	16.5831	6.5030
221	48841	10793861	14.8661	6.0459	276	76176	21024576	16.6132	6.5108
222	49284	10941048	14.8997	6.0550	277	76729	21253933	16.6433	6.5187
223	49729	11089567	14.9332	6.0641	278	77284	21484952	16.6733	6.5265
224	50176	11239424	14.9666	6.0732	279	77841	21717639	16.7033	6.5343
225	50625	11390625	15.0000	6.0822	280	78400	21952000	16.7332	6.5421
226	51076	11543176	15.0333	6.0912	281	78961	22188041	16.7631	6.5499
227	51529	11697083	15.0665	6.1002	282	79524	22425768	16.7929	6.5577
228	51984	11852352	15.0997	6.1091	283	80089	22665187	16.8226	6.5654
229	52441	12008989	15.1327	6.1180	284	80656	22906304	16.8523	6.5731
230	52900	12167000	15.1658	6.1269	285	81225	23149125	16.8819	6.5808
231	53361	12326391	15.1987	6.1358	286	81796	23393656	16.9115	6.5885
232	53824	12487168	15.2315	6.1446	287	82369	23639903	16.9411	6.5962
233	54289	12649337	15.2643	6.1534	288	82944	23887872	16.9706	6.6039
234	54756	12812904	15.2971	6.1622	289	83521	24137569	17.0000	6.6115
235	55225	12977875	15.3297	6.1710	290	84100	24389000	17.0294	6.6191
236	55696	13144256	15.3623	6.1797	291	84681	24642171	17.0587	6.6267
237	56169	13312053	15.3948	6.1885	292	85264	24897088	17.0880	6.6343
238	56644	13481272	15.4272	6.1972	293	85849	25153757	17.1172	6.6419
239	57121	13651919	15.4596	6.2058	294	86436	25412184	17.1464	6.6494
240	57600	13824000	15.4919	6.2145	295	87025	25672375	17.1756	6.6569
241	58081	13997521	15.5242	6.2231	296	87616	25934336	17.2047	6.6644
242	58564	14172488	15.5563	6.2317	297	88209	26198073	17.2337	6.6719
243	59049	14348907	15.5885	6.2403	298	88804	26463592	17.2627	6.6794
244	59536	14526784	15.6205	6.2488	299	89401	26730899	17.2916	6.6869
245	60025	14706125	15.6525	6.2573	300	90000	27000000	17.3205	6.6943
246	60516	14886936	15.6844	6.2658	301	90601	27270901	17.3494	6.7018
247	61009	15069223	15.7162	6.2743	302	91204	27543608	17.3781	6.7092
248	61504	15252992	15.7480	6.2828	303	91809	27818127	17.4069	6.7166
249	62001	15438249	15.7797	6.2912	304	92416	28094464	17.4356	6.7240
250	62500	15625000	15.8114	6.2996	305	93025	28372625	17.4642	6.7313
251	63001	15813251	15.8430	6.3080	306	93636	28652616	17.4929	6.7387
252	63504	16003008	15.8745	6.3164	307	94249	28934443	17.5214	6.7460
253	64009	16194277	15.9060	6.3247	308	94864	29218112	17.5499	6.7533
254	64516	16387064	15.9374	6.3330	309	95481	29503629	17.5784	6.7606
255	65025	16581375	15.9687	6.3413	310	96100	29791000	17.6068	6.7679
256	65536	16777216	16.0000	6.3496	311	96721	30080231	17.6352	6.7752
257	66049	16974593	16.0312	6.3579	312	97344	30371328	17.6635	6.7824
258	66564	17173512	16.0624	6.3661	313	97969	30664297	17.6918	6.7897
259	67081	17373979	16.0935	6.3743	314	98596	30959144	17.7200	6.7969
260	67600	17576000	16.1245	6.3825	315	99225	31255875	17.7482	6.8041
261	68121	17779581	16.1555	6.3907	316	99856	31554496	17.7764	6.8113
262	68644	17984728	16.1864	6.3988	317	100489	31855013	17.8045	6.8185
263	69169	18191447	16.2173	6.4070	318	101124	32157432	17.8326	6.8256
264	69696	18399744	16.2481	6.4151	319	101761	32461759	17.8606	6.8328

No.	Square.	Cube.	Sq. Root.	Cube Root.	No.	Square	Cube.	Sq. Root.	Cube Root.
320	102400	32768000	17.8885	6.8399	375	140625	52734375	19.3649	7.2112
321	103041	33076161	17.9165	6.8470	376	141376	53157376	19.3907	7.2177
322	103684	33386248	17.9444	6.8541	377	142129	53582633	19.4165	7.2240
323	104329	33698267	17.9722	6.8612	378	142884	54010152	19.4422	7.2304
324	104976	34012224	18.0000	6.8683	379	143641	54439939	19.4679	7.2368
325	105625	34328125	18.0278	6.8753	380	144400	54872000	19.4936	7.2432
326	106276	34645976	18.0555	6.8824	381	145161	55306341	19.5192	7.2495
327	106929	34965783	18.0831	6.8894	382	145924	55742968	19.5448	7.2558
328	107584	35287552	18.1108	6.8964	383	146689	56181887	19.5704	7.2622
329	108241	35611289	18.1384	6.9034	384	147456	56623104	19.5959	7.2685
330	108900	35937000	18.1659	6.9104	385	148225	57066625	19.6214	7.2748
331	109561	36264691	18.1934	6.9174	386	148996	57512456	19.6469	7.2811
332	110224	36594368	18.2209	6.9244	387	149769	57960603	19.6723	7.2874
333	110889	36926037	18.2483	6.9313	388	150544	58411072	19.6977	7.2936
334	111556	37259704	18.2757	6.9382	389	151321	58863869	19.7231	7.2999
335	112225	37595375	18.3030	6.9451	390	152100	59319000	19.7484	7.3061
336	112896	37933056	18.3303	6.9521	391	152881	59776471	19.7737	7.3124
337	113569	38272753	18.3576	6.9589	392	153664	60236288	19.7990	7.3186
338	114244	38614472	18.3848	6.9658	393	154449	60698457	19.8242	7.3248
339	114921	38958219	18.4120	6.9727	394	155236	61162984	19.8494	7.3310
340	115600	39304000	18.4391	6.9795	395	156025	61629875	19.8746	7.3372
341	116281	39651821	18.4662	6.9864	396	156816	62099136	19.8997	7.3434
342	116964	40001688	18.4932	6.9932	397	157609	62570773	19.9249	7.3496
343	117649	40353607	18.5203	7.0000	398	158404	63044792	19.9499	7.3558
344	118336	40707584	18.5472	7.0068	399	159201	63521199	19.9750	7.3619
345	119025	41063625	18.5742	7.0136	400	160000	64000000	20.0000	7.3681
346	119716	41421736	18.6011	7.0203	401	160801	64481201	20.0250	7.3742
347	120409	41781923	18.6279	7.0271	402	161604	64964808	20.0499	7.3803
348	121104	42144192	18.6548	7.0338	403	162409	65450827	20.0749	7.3864
349	121801	42508549	18.6815	7.0406	404	163216	65939264	20.0998	7.3925
350	122500	42875000	18.7083	7.0473	405	164025	66430125	20.1246	7.3986
351	123201	43243551	18.7350	7.0540	406	164836	66923416	20.1494	7.4047
352	123904	43614208	18.7617	7.0607	407	165649	67419143	20.1742	7.4108
353	124609	43986977	18.7883	7.0674	408	166464	67917312	20.1990	7.4169
354	125316	44361864	18.8149	7.0740	409	167281	68417929	20.2237	7.4229
355	126025	44738875	18.8414	7.0807	410	168100	68921000	20.2485	7.4290
356	126736	45118016	18.8680	7.0873	411	168921	69426531	20.2731	7.4350
357	127449	45499293	18.8944	7.0940	412	169744	69934528	20.2978	7.4410
358	128164	45882712	18.9209	7.1006	413	170569	70444997	20.3224	7.4470
359	128881	46268279	18.9473	7.1072	414	171396	70957944	20.3470	7.4530
360	129600	46656000	18.9737	7.1138	415	172225	71473375	20.3715	7.4590
361	130321	47045881	19.0000	7.1204	416	173056	71991296	20.3961	7.4650
362	131044	47437928	19.0263	7.1269	417	173889	72511713	20.4206	7.4710
363	131769	47832147	19.0526	7.1335	418	174724	73034632	20.4450	7.4770
364	132496	48228544	19.0788	7.1400	419	175561	73560059	20.4695	7.4829
365	133225	48627125	19.1050	7.1466	420	176400	74088000	20.4939	7.4889
366	133956	49027896	19.1311	7.1531	421	177241	74618461	20.5183	7.4948
367	134689	49430863	19.1572	7.1596	422	178084	75151448	20.5426	7.5007
368	135424	49836032	19.1833	7.1661	423	178929	75686967	20.5670	7.5067
369	136161	50243409	19.2094	7.1726	424	179776	76225024	20.5913	7.5126
370	136900	50653000	19.2354	7.1791	425	180625	76765625	20.6155	7.5185
371	137641	51064811	19.2614	7.1855	426	181476	77308776	20.6398	7.5244
372	138384	51478848	19.2873	7.1920	427	182329	77854483	20.6640	7.5302
373	139129	51895117	19.3132	7.1984	428	183184	78402752	20.6882	7.5361
374	139876	52313624	19.3391	7.2048	429	184041	78953589	20.7123	7.5420

No.	Square	Cube.	Sq. Root.	Cube Root.
430	184900	79507000	20.7364	7.5478
431	185761	80062991	20.7605	7.5537
432	186624	80621568	20.7846	7.5595
433	187489	81182737	20.8087	7.5654
434	188356	81746504	20.8327	7.5712
435	189225	82312875	20.8567	7.5770
436	190096	82881856	20.8806	7.5828
437	190969	83453453	20.9045	7.5886
438	191844	84027672	20.9284	7.5944
439	192721	84604519	20.9523	7.6001
440	193600	85184000	20.9762	7.6059
441	194481	85766121	21.0000	7.6117
442	195364	86350888	21.0238	7.6174
443	196249	86938307	21.0476	7.6232
444	197136	87528384	21.0713	7.6289
445	198025	88121125	21.0950	7.6346
446	198916	88716536	21.1187	7.6403
447	199809	89314623	21.1424	7.6460
448	200704	89915392	21.1660	7.6517
449	201601	90518849	21.1896	7.6574
450	202500	91125000	21.2132	7.6631
451	203401	91733851	21.2368	7.6688
452	204304	92345408	21.2603	7.6744
453	205209	92959677	21.2838	7.6800
454	206116	93576664	21.3073	7.6857
455	207025	94196375	21.3307	7.6914
456	207936	94818816	21.3542	7.6970
457	208849	95443993	21.3776	7.7026
458	209764	96071912	21.4009	7.7082
459	210681	96702579	21.4243	7.7138
460	211600	97336000	21.4476	7.7194
461	212521	97972181	21.4709	7.7250
462	213444	98611128	21.4942	7.7306
463	214369	99252847	21.5174	7.7362
464	215296	99897344	21.5407	7.7418
465	216225	100544625	21.5639	7.7473
466	217156	101194696	21.5870	7.7529
467	218089	101847563	21.6102	7.7584
468	219024	102503232	21.6333	7.7639
469	219961	103161709	21.6564	7.7695
470	220900	103823000	21.6795	7.7750
471	221841	104487111	21.7025	7.7805
472	222784	105154048	21.7256	7.7860
473	223729	105823817	21.7486	7.7915
474	224676	106496424	21.7715	7.7970
475	225625	107171875	21.7945	7.8025
476	226576	107850176	21.8174	7.8079
477	227529	108531333	21.8403	7.8134
478	228484	109215352	21.8632	7.8188
479	229441	109902239	21.8861	7.8243
480	230400	110592000	21.9089	7.8297
481	231361	111284641	21.9317	7.8352
482	232324	111980168	21.9545	7.8406
483	233289	112678587	21.9773	7.8460
484	234256	113379904	22.0000	7.8514
485	235225	114084125	22.0227	7.8568
486	236196	114791256	22.0454	7.8622
487	237169	115501303	22.0681	7.8676
488	238144	116214272	22.0907	7.8730
489	239121	116930169	22.1133	7.8784
490	240100	117649000	22.1359	7.8837
491	241081	118370771	22.1585	7.8891
492	242064	119095488	22.1811	7.8944
493	243049	119823157	22.2036	7.8998
494	244036	120553784	22.2261	7.9051
495	245025	121287375	22.2486	7.9105
496	246016	122023936	22.2711	7.9158
497	247009	122763473	22.2935	7.9211
498	248004	123505992	22.3159	7.9264
499	249001	124251499	22.3383	7.9317
500	250000	125000000	22.3607	7.9370
501	251001	125751501	22.3830	7.9423
502	252004	126506008	22.4054	7.9476
503	253009	127263527	22.4277	7.9528
504	254016	128024064	22.4499	7.9581
505	255025	128787625	22.4722	7.9634
506	256036	129554216	22.4944	7.9686
507	257049	130323843	22.5167	7.9739
508	258064	131096512	22.5389	7.9791
509	259081	131872229	22.5610	7.9843
510	260100	132651000	22.5832	7.9896
511	261121	133432831	22.6053	7.9948
512	262144	134217728	22.6274	8.0000
513	263169	135005697	22.6495	8.0052
514	264196	135796744	22.6716	8.0104
515	265225	136590875	22.6936	8.0156
516	266256	137388096	22.7156	8.0208
517	267289	138188413	22.7376	8.0260
518	268324	138991832	22.7596	8.0311
519	269361	139798359	22.7816	8.0363
520	270400	140608000	22.8035	8.0415
521	271441	141420761	22.8254	8.0466
522	272484	142236648	22.8473	8.0517
523	273529	143055667	22.8692	8.0569
524	274576	143877824	22.8910	8.0620
525	275625	144703125	22.9129	8.0671
526	276676	145531576	22.9347	8.0723
527	277729	146363183	22.9565	8.0774
528	278784	147197952	22.9783	8.0825
529	279841	148035889	23.0000	8.0876
530	280900	148877000	23.0217	8.0927
531	281961	149721291	23.0434	8.0978
532	283024	150568768	23.0651	8.1028
533	284089	151419437	23.0868	8.1079
534	285156	152273304	23.1084	8.1130
535	286225	153130375	23.1301	8.1180
536	287296	153990656	23.1517	8.1231
537	288369	154854153	23.1733	8.1281
538	289444	155720872	23.1948	8.1332
539	290521	156590819	23.2164	8.1382

No.	Square.	Cube.	Sq. Root.	Cube Root.	No.	Square	Cube.	Sq. Root.	Cube Root.
540	291600	157464000	23.2379	8.1433	595	354025	210644875	24.3926	8.4108
541	292681	158340421	23.2594	8.1483	596	355216	211708736	24.4131	8.4155
542	293764	159220088	23.2809	8.1533	597	356409	212776173	24.4336	8.4202
543	294849	160103007	23.3024	8.1583	598	357604	213847192	24.4540	8.4249
544	295936	160989184	23.3238	8.1633	599	358801	214921799	24.4745	8.4296
545	297025	161878625	23.3452	8.1683	600	360000	216000000	24.4949	8.4343
546	298116	162771336	23.3666	8.1733	601	361201	217081801	24.5153	8.4390
547	299209	163667323	23.3880	8.1783	602	362404	218167208	24.5357	8.4437
548	300304	164566592	23.4094	8.1833	603	363609	219256227	24.5561	8.4484
549	301401	165469149	23.4307	8.1882	604	364816	220348864	24.5764	8.4530
550	302500	166375000	23.4521	8.1932	605	366025	221445125	24.5967	8.4577
551	303601	167284151	23.4734	8.1982	606	367236	222545016	24.6171	8.4623
552	304704	168196608	23.4947	8.2031	607	368449	223648543	24.6374	8.4670
553	305809	169112377	23.5160	8.2081	608	369664	224755712	24.6577	8.4716
554	306916	170031464	23.5372	8.2130	609	370881	225866529	24.6779	8.4763
555	308025	170953875	23.5584	8.2180	610	372100	226981000	24.6982	8.4809
556	309136	171879616	23.5797	8.2229	611	373321	228099131	24.7184	8.4856
557	310249	172808693	23.6008	8.2278	612	374544	229220928	24.7386	8.4902
558	311364	173741112	23.6220	8.2327	613	375769	230346397	24.7588	8.4948
559	312481	174676879	23.6432	8.2377	614	376996	231475544	24.7790	8.4994
560	313600	175616000	23.6643	8.2426	615	378225	232608375	24.7992	8.5040
561	314721	176558481	23.6854	8.2475	616	379456	233744896	24.8193	8.5086
562	315844	177504328	23.7065	8.2524	617	380689	234885113	24.8395	8.5132
563	316969	178453547	23.7276	8.2573	618	381924	236029032	24.8596	8.5178
564	318096	179406144	23.7487	8.2621	619	383161	237176659	24.8797	8.5224
565	319225	180362125	23.7697	8.2670	620	384400	238328000	24.8998	8.5270
566	320356	181321496	23.7908	8.2719	621	385641	239483061	24.9199	8.5316
567	321489	182284263	23.8118	8.2768	622	386884	240641848	24.9399	8.5362
568	322624	183250432	23.8328	8.2816	623	388129	241804367	24.9600	8.5408
569	323761	184220009	23.8537	8.2865	624	389376	242970624	24.9800	8.5453
570	324900	185193000	23.8747	8.2913	625	390625	244140625	25.0000	8.5499
571	326041	186169411	23.8956	8.2962	626	391876	245314376	25.0200	8.5544
572	327184	187149248	23.9165	8.3010	627	393129	246491883	25.0400	8.5590
573	328329	188132517	23.9374	8.3059	628	394384	247673152	25.0599	8.5635
574	329476	189119224	23.9583	8.3107	629	395641	248858189	25.0799	8.5681
575	330625	190109375	23.9792	8.3155	630	396900	250047000	25.0998	8.5726
576	331776	191102976	24.0000	8.3203	631	398161	251239591	25.1197	8.5772
577	332929	192100033	24.0208	8.3251	632	399424	252435968	25.1396	8.5817
578	334084	193100552	24.0416	8.3300	633	400689	253636137	25.1595	8.5862
579	335241	194104539	24.0624	8.3348	634	401956	254840104	25.1794	8.5907
580	336400	195112000	24.0832	8.3396	635	403225	256047875	25.1992	8.5952
581	337561	196122941	24.1039	8.3443	636	404496	257259456	25.2190	8.5997
582	338724	197137368	24.1247	8.3491	637	405769	258474853	25.2389	8.6043
583	339889	198155287	24.1454	8.3539	638	407044	259694072	25.2587	8.6088
584	341056	199176704	24.1661	8.3587	639	408321	260917119	25.2784	8.6132
585	342225	200201625	24.1868	8.3634	640	409600	262144000	25.2982	8.6177
586	343396	201230056	24.2074	8.3682	641	410881	263374721	25.3180	8.6222
587	344569	202262003	24.2281	8.3730	642	412164	264609288	25.3377	8.6267
588	345744	203297472	24.2487	8.3777	643	413449	265847707	25.3574	8.6312
589	346921	204336469	24.2693	8.3825	644	414736	267089984	25.3772	8.6357
590	348100	205379000	24.2899	8.3872	645	416025	268336125	25.3969	8.6401
591	349281	206425071	24.3105	8.3919	646	417316	269586136	25.4165	8.6446
592	350464	207474688	24.3311	8.3967	647	418609	270840023	25.4362	8.6490
593	351649	208527857	24.3516	8.4014	648	419904	272097792	25.4558	8.6535
594	352836	209584584	24.3721	8.4061	649	421201	273359449	25.4755	8.6579

No.	Square.	Cube.	Sq. Root.	Cube Root.	No.	Square	Cube.	Sq. Root.	Cube Root.
650	422500	274625000	25.4951	8.6624	705	497025	350402625	26.5518	8.9001
651	423801	275894451	25.5147	8.6668	706	498436	351895816	26.5707	8.9043
652	425104	277167808	25.5343	8.6713	707	499849	353393243	26.5895	8.9085
653	426409	278445077	25.5539	8.6757	708	501264	354894912	26.6083	8.9127
654	427716	279726264	25.5734	8.6801	709	502681	356400829	26.6271	8.9169
655	429025	281011375	25.5930	8.6845	710	504100	357911000	26.6458	8.9211
656	430336	282300416	25.6125	8.6890	711	505521	359425431	26.6646	8.9253
657	431649	283593393	25.6320	8.6934	712	506944	360944128	26.6833	8.9295
658	432964	284890312	25.6515	8.6978	713	508369	362467097	26.7021	8.9337
659	434281	286191179	25.6710	8.7022	714	509796	363994344	26.7208	8.9378
660	435600	287496000	25.6905	8.7066	715	511225	365525875	26.7395	8.9420
661	436921	288804781	25.7099	8.7110	716	512656	367061696	26.7582	8.9462
662	438244	290117528	25.7294	8.7154	717	514089	368601813	26.7769	8.9503
663	439569	291434247	25.7488	8.7198	718	515524	370146232	26.7955	8.9545
664	440896	292754944	25.7682	8.7241	719	516961	371694959	26.8142	8.9587
665	442225	294079625	25.7876	8.7285	720	518400	373248000	26.8328	8.9628
666	443556	295408296	25.8070	8.7329	721	519841	374805361	26.8514	8.9670
667	444889	296740963	25.8263	8.7373	722	521284	376367048	26.8701	8.9711
668	446224	298077632	25.8457	8.7416	723	522729	377933067	26.8887	8.9752
669	447561	299418309	25.8650	8.7460	724	524176	379503424	26.9072	8.9794
670	448900	300763000	25.8844	8.7503	725	525625	381078125	26.9258	8.9835
671	450241	302111711	25.9037	8.7547	726	527076	382657176	26.9444	8.9876
672	451584	303464448	25.9230	8.7590	727	528529	384240583	26.9629	8.9918
673	452929	304821217	25.9422	8.7634	728	529984	385828352	26.9815	8.9959
674	454276	306182024	25.9615	8.7677	729	531441	387420489	27.0000	9 0000
675	455625	307546875	25.9808	8.7721	730	532900	389017000	27.0185	9.0041
676	456976	308915776	26.0000	8.7764	731	534361	390617891	27.0370	9.0082
677	458329	310288733	26.0192	8.7807	732	535824	392223168	27.0555	9.0123
678	459684	311665752	26.0384	8.7850	733	537289	393832837	27.0740	9.0164
679	461041	313046839	26.0576	8.7893	734	538756	395446904	27.0924	9.0205
680	462400	314432000	26.0768	8.7937	735	540225	397065375	27.1109	9.0246
681	463761	315821241	26.0960	8.7980	736	541696	398688256	27.1293	9.0287
682	465124	317214568	26.1151	8.8023	737	543169	400315553	27.1477	9.0328
683	466489	318611987	26.1343	8.8066	738	544644	401947272	27.1662	9.0369
684	467856	320013504	26.1534	8.8109	739	546121	403583419	27.1846	9.0410
685	469225	321419125	26.1725	8.8152	740	547600	405224000	27.2029	9.0450
686	470596	322828856	26.1916	8.8194	741	549081	406869021	27.2213	9.0491
687	471969	324242703	26.2107	8.8237	742	550564	408518488	27.2397	9.0532
688	473344	325660672	26.2298	8.8280	743	552049	410172407	27.2580	9.0572
689	474721	327082769	26.2488	8.8323	744	553536	411830784	27.2764	9.0613
690	476100	328509000	26.2679	8.8366	745	555025	413493625	27.2947	9.0654
691	477481	329939371	26.2869	8.8408	746	556516	415160936	27.3130	9.0694
692	478864	331373888	26.3059	8.8451	747	558009	416832723	27.3313	9.0735
693	480249	332812557	26.3249	8.8493	748	559504	418508992	27.3496	9.0775
694	481636	334255384	26.3439	8.8536	749	561001	420189749	27.3679	9.0816
695	483025	335702375	26.3629	8.8578	750	562500	421875000	27.3861	9.0856
696	484416	337153536	26.3818	8.8621	751	564001	423564751	27.4044	9 0896
697	485809	338608873	26.4008	8.8663	752	565504	425259008	27.4226	9.0937
698	487204	340068392	26.4197	8.8706	753	567009	426957777	27.4408	9.0977
699	488601	341532099	26.4386	8.8748	754	568516	428661064	27.4591	9.1017
700	490000	343000000	26.4575	8.8790	755	570025	430368875	27.4773	9.1057
701	491401	344472101	26.4764	8.8833	756	571536	432081216	27.4955	9.1098
702	492804	345948408	26.4953	8.8875	757	573049	433798093	27.5136	9.1138
703	494209	347428927	26.5141	8.8917	758	574564	435519512	27.5318	9.1178
704	495616	348913664	26.5330	8.8959	759	576081	437245479	27.5500	9.1218

No.	Square.	Cube.	Sq. Root.	Cube Root.	No.	Square	Cube.	Sq. Root.	Cube Root.
760	577600	438976000	27.5681	9.1258	815	664225	541343375	28.5482	9.3408
761	579121	440711081	27.5862	9.1298	816	665856	543338496	28.5657	9.3447
762	580644	442450728	27.6043	9.1338	817	667489	545338513	28.5832	9.3485
763	582169	444194947	27.6225	9.1378	818	669124	547343432	28.6007	9.3523
764	583696	445943744	27.6405	9.1418	819	670761	549353259	28.6182	9.3561
765	585225	447697125	27.6586	9.1458	820	672400	551368000	28.6356	9.3599
766	586756	449455096	27.6767	9.1498	821	674041	553387661	28.6531	9.3637
767	588289	451217663	27.6948	9.1537	822	675684	555412248	28.6705	9.3675
768	589824	452984832	27.7128	9.1577	823	677329	557441767	28.6880	9.3713
769	591361	454756609	27.7308	9.1617	824	678976	559476224	28.7054	9.3751
770	592900	456533000	27.7489	9.1657	825	680625	561515625	28.7228	9.3789
771	594441	458314011	27.7669	9.1696	826	682276	563559976	28.7402	9.3827
772	595984	460099648	27.7849	9.1736	827	683929	565609283	28.7576	9.3865
773	597529	461889917	27.8029	9.1775	828	685584	567663552	28.7750	9.3902
774	599076	463684824	27.8209	9.1815	829	687241	569722789	28.7924	9.3940
775	600625	465484375	27.8388	9.1855	830	688900	571787000	28.8097	9.3978
776	602176	467288576	27.8568	9.1894	831	690561	573856191	28.8271	9.4016
777	603729	469097433	27.8747	9.1933	832	692224	575930368	28.8444	9.4053
778	605284	470910952	27.8927	9.1973	833	693889	578009537	28.8617	9.4091
779	606841	472729139	27.9106	9.2012	834	695556	580093704	28.8791	9.4129
780	608400	474552000	27.9285	9.2052	835	697225	582182875	28.8964	9.4166
781	609961	476379541	27.9464	9.2091	836	698896	584277056	28.9137	9.4204
782	611524	478211768	27.9643	9.2130	837	700569	586376253	28.9310	9.4241
783	613089	480048687	27.9821	9.2170	838	702244	588480472	28.9482	9.4279
784	614656	481890304	28.0000	9.2209	839	703921	590589719	28.9655	9.4316
785	616225	483736625	28.0179	9.2248	840	705600	592704000	28.9828	9.4354
786	617796	485587656	28.03[illegible]7	9.2287	841	707281	594823321	29.0000	9.4391
787	619369	487443403	28.0535	9.2326	842	708964	596947688	29.0172	9.4429
788	620944	489303872	28.0713	9.2365	843	710649	599077107	29.0345	9.4466
789	622521	491169069	28.0891	9.2404	844	712336	601211584	29.0517	9.4503
790	624100	493039000	28.1069	9.2443	845	714025	603351125	29.0689	9.4541
791	625681	494913[illegible]71	28.1247	9.2482	846	715716	605495736	29.0861	9.4578
792	627264	496793088	28.1425	9.2521	847	717409	607645423	29.1033	9.4615
793	628849	498677257	28.1603	[illegible].2560	848	719104	609800192	29.1204	9.4652
794	630436	500566184	28.1780	9.2599	849	720801	611960049	29.1376	9.4690
795	632025	502459875	28.1957	9.2638	850	722500	614125000	29.1548	9.4727
796	633616	504358336	28.2135	9.2677	851	724201	616295051	29.1719	9.4764
797	635209	5062[illegible]1573	28.2312	9.2716	852	725904	618470208	29.1890	9.4801
798	636804	508169592	28.2489	9.2754	853	727609	620650477	29.2062	9.4838
799	638401	510082399	28.2666	9.2793	854	729316	622835864	29.2233	9.4875
800	640000	512000000	28.2843	9.2832	855	731025	625026375	29.2404	9.4912
801	641601	513922401	28.3019	9.2870	856	732736	627222016	29.2575	9.4949
802	643204	515849608	28.3196	9.2909	857	734449	629422793	29.2746	9.4986
803	644809	517781627	28.3373	9.2948	858	736164	631628712	29.2916	9.5023
804	646416	519718464	28.3549	9.2986	859	737881	633839779	29.3087	9.5060
805	648025	521660125	28.3725	9.3025	860	739600	636056000	29.3258	9.5097
806	649636	523606616	28.3901	9.3063	861	741321	638277381	29.3428	9.5134
807	651249	525557943	28.4077	9.3102	862	743044	640503928	29.3598	9.5171
808	652864	527514112	28.4253	9.3140	863	744769	642735647	29.3769	9.5207
809	654481	529475129	28.4429	9.3179	864	746496	644972544	29.3939	9.5244
810	656100	531441000	28.4605	9.3217	865	748225	647214625	29.4109	9.5281
811	657721	533411731	28.4781	9.3255	866	749956	649461896	29.4279	9.5317
812	659344	535387328	28.4956	9.3294	867	751689	651714363	29.4449	9.5354
813	660969	537367797	28.5132	9.3332	868	753424	653972032	29.4618	9.5391
814	662596	539353144	28.5307	9.3370	869	755161	656234909	29.4788	9.5427

No.	Square.	Cube.	Sq. Root.	Cube Root.	No.	Square	Cube.	Sq. Root.	Cube Root.
870	756900	658503000	29.4958	9.5464	925	855625	791453125	30.4138	9.7435
871	758641	660776311	29.5127	9.5501	926	857476	794022776	30.4302	9.7470
872	760384	663054848	29.5296	9.5537	927	859329	796597983	30.4467	9.7505
873	762129	665338617	29.5466	9.5574	928	861184	799178752	30.4631	9.7540
874	763876	667627624	29.5635	9.5610	929	863041	801765089	30.4795	9.7575
875	765625	669921875	29.5804	9.5647	930	864900	804357000	30.4959	9.7610
876	767376	672221376	29.5973	9.5683	931	866761	806954491	30.5123	9.7645
877	769129	674526133	29.6142	9.5719	932	868624	809557568	30.5287	9.7680
878	770884	676836152	29.6311	9.5756	933	870489	812166237	30.5450	9.7715
879	772641	679151439	29.6479	9.5792	934	872356	814780504	30.5614	9.7750
880	774400	681472000	29.6648	9.5828	935	874225	817400375	30.5778	9.7785
881	776161	683797841	29.6816	9.5865	936	876096	820025856	30.5941	9.7819
882	777924	686128968	29.6985	9.5901	937	877969	822656953	30.6105	9.7854
883	779689	688465387	29.7153	9.5937	938	879844	825293672	30.6268	9.7889
884	781456	690807104	29.7321	9.5973	939	881721	827936019	30.6431	9.7924
885	783225	693154125	29.7489	9.6010	940	883600	830584000	30.6594	9.7959
886	784996	695506456	29.7658	9.6046	941	885481	833237621	30.6757	9.7993
887	786769	697864103	29.7825	9.6082	942	887364	835896888	30.6920	9.8028
888	788544	700227072	29.7993	9.6118	943	889249	838561807	30.7083	9.8063
889	790321	702595369	29.8161	9.6154	944	891136	841232384	30.7246	9.8097
890	792100	704969000	29.8329	9.6190	945	893025	843908625	30.7409	9.8132
891	793881	707347971	29.8496	9.6226	946	894916	846590536	30.7571	9.8167
892	795664	709732288	29.8664	9.6262	947	896809	849278123	30.7734	9.8201
893	797449	712121957	29.8831	9.6298	948	898704	851971392	30.7896	9.8236
894	799236	714516984	29.8998	9.6334	949	900601	854670349	30.8058	9.8270
895	801025	716917375	29.9166	9.6370	950	902500	857375000	30.8221	9.8305
896	802816	719323136	29.9333	9.6406	951	904401	860085351	30.8383	9.8339
897	804609	721734273	29.9500	9.6442	952	906304	862801408	30.8545	9.8374
898	806404	724150792	29.9666	9.6477	953	908209	865523177	30.8707	9.8408
899	808201	726572699	29.9833	9.6513	954	910116	868250664	30.8869	9.8443
900	810000	729000000	30.0000	9.6549	955	912025	870983875	30.9031	9.8477
901	811801	731432701	30.0167	9.6585	956	913936	873722816	30.9192	9.8511
902	813604	733870808	30.0333	9.6620	957	915849	876467493	30.9354	9.8546
903	815409	736314327	30.0500	9.6656	958	917764	879217912	30.9516	9.8580
904	817216	738763264	30.0666	9.6692	959	919681	881974079	30.9677	9.8614
905	819025	741217625	30.0832	9.6727	960	921600	884736000	30.9839	9.8648
906	820836	743677416	30.0998	9.6763	961	923521	887503681	31.0000	9.8683
907	822649	746142643	30.1164	9.6799	962	925444	890277128	31.0161	9.8717
908	824464	748613312	30.1330	9.6834	963	927369	893056347	31.0322	9.8751
909	826281	751089429	30.1496	9.6870	964	929296	895841344	31.0483	9.8785
910	828100	753571000	30.1662	9.6905	965	931225	898632125	31.0644	9.8819
911	829921	756058031	30.1828	9.6941	966	933156	901428696	31.0805	9.8854
912	831744	758550528	30.1993	9.6976	967	935089	904231063	31.0966	9.8888
913	833569	761048497	30.2159	9.7012	968	937024	907039232	31.1127	9.8922
914	835396	763551944	30.2324	9.7047	969	938961	909853209	31.1288	9.8956
915	837225	766060875	30.2490	9.7082	970	940900	912673000	31.1448	9.8990
916	839056	768575296	30.2655	9.7118	971	942841	915498611	31.1609	9.9024
917	840889	771095213	30.2820	9.7153	972	944784	918330048	31.1769	9.9058
918	842724	773620632	30.2985	9.7188	973	946729	921167317	31.1929	9.9092
919	844561	776151559	30.3150	9.7224	974	948676	924010424	31.2090	9.9126
920	846400	778688000	30.3315	9.7259	975	950625	926859375	31.2250	9.9160
921	848241	781229961	30.3480	9.7294	976	952576	929714176	31.2410	9.9194
922	850084	783777448	30.3645	9.7329	977	954529	932574833	31.2570	9.9227
923	851929	786330467	30.3809	9.7364	978	956484	935441352	31.2730	9.9261
924	853776	788889024	30.3974	9.7400	979	958441	938313739	31.2890	9.9295

No.	Square.	Cube.	Sq. Root.	Cube Root.	No.	Square.	Cube.	Sq. Root.	Cube Root.
980	960400	941192000	31.3050	9.9329	1035	1071225	1108717875	32.1714	10.1153
981	962361	944076141	31.3209	9.9363	1036	1073296	1111934656	32.1870	10.1186
982	964324	946966168	31.3369	9.9396	1037	1075369	1115157653	32.2025	10.1218
983	966289	949862087	31.3528	9.9430	1038	1077444	1118386872	32.2180	10.1251
984	968256	952763904	31.3688	9.9464	1039	1079521	1121622319	32.2335	10.1283
985	970225	955671625	31.3847	9.9497	1040	1081600	1124864000	32.2490	10.1316
986	972196	958585256	31.4006	9.9531	1041	1083681	1128111921	32.2645	10.1348
987	974169	961504803	31.4166	9.9565	1042	1085764	1131366088	32.2800	10.1381
988	976144	964430272	31.4325	9.9598	1043	1087849	1134626507	32.2955	10.1413
989	978121	967361569	31.4484	9.9632	1044	1089936	1137893184	32.3110	10.1446
990	980100	970299000	31.4643	9.9666	1045	1092025	1141166125	32.3265	10.1478
991	982081	973242271	31.4802	9.9699	1046	1094116	1144445336	32.3419	10.1510
992	984064	976191488	31.4960	9.9733	1047	1096209	1147730823	32.3574	10.1543
993	986049	979146657	31.5119	9.9766	1048	1098304	1151022592	32.3728	10.1575
994	988036	982107784	31.5278	9.9800	1049	1100401	1154320649	32.3883	10.1607
995	990025	985074875	31.5436	9.9833	1050	1102500	1157625000	32.4037	10.1640
996	992016	988047936	31.5595	9.9866	1051	1104601	1160935651	32.4191	10.1672
997	994009	991026973	31.5753	9.9900	1052	1106704	1164252608	32.4345	10.1704
998	996004	994011992	31.5911	9.9933	1053	1108809	1167575877	32.4500	10.1736
999	998001	997002999	31.6070	9.9967	1054	1110916	1170905464	32.4654	10.1769
1000	1000000	1000000000	31.6228	10.0000	1055	1113025	1174241375	32.4808	10.1801
1001	1002001	1003003001	31.6386	10.0033	1056	1115136	1177583616	32.4962	10.1833
1002	1004004	1006012008	31.6544	10.0067	1057	1117249	1180932193	32.5115	10.1865
1003	1006009	1009027027	31.6702	10.0100	1058	1119364	1184287112	32.5269	10.1897
1004	1008016	1012048064	31.6860	10.0133	1059	1121481	1187648379	32.5423	10.1929
1005	1010025	1015075125	31.7017	10.0166	1060	1123600	1191016000	32.5576	10.1961
1006	1012036	1018108216	31.7175	10.0200	1061	1125721	1194389981	32.5730	10.1993
1007	1014049	1021147343	31.7333	10.0233	1062	1127844	1197770328	32.5883	10.2025
1008	1016064	1024192512	31.7490	10.0266	1063	1129969	1201157047	32.6036	10.2057
1009	1018081	1027243729	31.7648	10.0299	1064	1132096	1204550144	32.6190	10.2089
1010	1020100	1030301000	31.7805	10.0332	1065	1134225	1207949625	32.6343	10.2121
1011	1022121	1033364331	31.7962	10.0365	1066	1136356	1211355496	32.6497	10.2153
1012	1024144	1036433728	31.8119	10.0398	1067	1138489	1214767763	32.6650	10.2185
1013	1026169	1039509197	31.8277	10.0431	1068	1140624	1218186432	32.6803	10.2217
1014	1028196	1042590744	31.8434	10.0465	1069	1142761	1221611509	32.6956	10.2249
1015	1030225	1045678375	31.8591	10.0498	1070	1144900	1225043000	32.7109	10.2281
1016	1032256	1048772096	31.8748	10.0531	1071	1147041	1228480911	32.7261	10.2313
1017	1034289	1051871913	31.8904	10.0563	1072	1149184	1231925248	32.7414	10.2345
1018	1036324	1054977832	31.9061	10.0596	1073	1151329	1235376017	32.7567	10.2376
1019	1038361	1058089859	31.9218	10.0629	1074	1153476	1238833224	32.7719	10.2408
1020	1040400	1061208000	31.9374	10.0662	1075	1155625	1242296875	32.7872	10.2440
1021	1042441	1064332261	31.9531	10.0695	1076	1157776	1245766976	32.8024	10.2472
1022	1044484	1067462648	31.9687	10.0728	1077	1159929	1249243533	32.8177	10.2503
1023	1046529	1070599167	31.9844	10.0761	1078	1162084	1252726552	32.8329	10.2535
1024	1048576	1073741824	32.0000	10.0794	1079	1164241	1256216039	32.8481	10.2567
1025	1050625	1076890625	32.0156	10.0826	1080	1166400	1259712000	32.8634	10.2599
1026	1052676	1080045576	32.0312	10.0859	1081	1168561	1263214441	32.8786	10.2630
1027	1054729	1083206683	32.0468	10.0892	1082	1170724	1266723368	32.8938	10.2662
1028	1056784	1086373952	32.0624	10.0925	1083	1172889	1270238787	32.9090	10.2693
1029	1058841	1089547389	32.0780	10.0957	1084	1175056	1273760704	32.9242	10.2725
1030	1060900	1092727000	32.0936	10.0990	1085	1177225	1277289125	32.9393	10.2757
1031	1062961	1095912791	32.1092	10.1023	1086	1179396	1280824056	32.9545	10.2788
1032	1065024	1099104768	32.1248	10.1055	1087	1181569	1284365503	32.9697	10.2820
1033	1067089	1102302937	32.1403	10.1088	1088	1183744	1287913472	32.9848	10.2851
1034	1069156	1105507304	32.1559	10.1121	1089	1185921	1291467969	33.0000	10.2883

CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Circum.	Area.
1/64	.04909	.00019
1/32	.09818	.00077
3/64	.14726	.00173
1/16	.19635	.00307
3/32	.29452	.00690
1/8	.39270	.01227
5/32	.49087	.01917
3/16	.58905	.02761
7/32	.68722	.03758
1/4	.78540	.04909
9/32	.88357	.06213
5/16	.98175	.07670
11/32	1.0799	.09281
3/8	1.1781	.11045
13/32	1.2763	.12962
7/16	1.3744	.15033
15/32	1.4726	.17257
1/2	1.5708	.19635
17/32	1.6690	.22166
9/16	1.7671	.24850
19/32	1.8653	.27688
5/8	1.9635	.30680
21/32	2.0617	.33824
11/16	2.1598	.37122
23/32	2.2580	.40574
3/4	2.3562	.44179
25/32	2.4544	.47937
13/16	2.5525	.51849
27/32	2.6507	.55914
7/8	2.7489	.60132
29/32	2.8471	.64504
15/16	2.9452	.69029
31/32	3.0434	.73708
1.	3.1416	.7854
1/16	3.3379	.8866
1/8	3.5343	.9940
3/16	3.7306	1.1075
1/4	3.9270	1.2272
5/16	4.1233	1.3530
3/8	4.3197	1.4849
7/16	4.5160	1.6230
1/2	4.7124	1.7671
9/16	4.9087	1.9175
5/8	5.1051	2.0739
11/16	5.3014	2.2365
3/4	5.4978	2.4053
13/16	5.6941	2.5802
7/8	5.8905	2.7612
15/16	6.0868	2.9483
2.	6.2832	3.1416
1/16	6.4795	3.3410
1/8	6.6759	3.5466
3/16	6.8722	3.7583
1/4	7.0686	3.9761
5/16	7.2649	4.2000

Diam.	Circum.	Area.
2 3/8	7.4613	4.4301
7/16	7.6576	4.6664
1/2	7.8540	4.9087
9/16	8.0503	5.1572
5/8	8.2467	5.4119
11/16	8.4430	5.6727
3/4	8.6394	5.9396
13/16	8.8357	6.2126
7/8	9.0321	6.4918
15/16	9.2284	6.7771
3.	9.4248	7.0686
1/16	9.6211	7.3662
1/8	9.8175	7.6699
3/16	10.014	7.9798
1/4	10.210	8.2958
5/16	10.407	8.6179
3/8	10.603	8.9462
7/16	10.799	9.2806
1/2	10.996	9.6211
9/16	11.192	9.9678
5/8	11.388	10.321
11/16	11.585	10.680
3/4	11.781	11.045
13/16	11.977	11.416
7/8	12.174	11.793
15/16	12.370	12.177
4.	12.566	12.566
1/16	12.763	12.962
1/8	12.959	13.364
3/16	13.155	13.772
1/4	13.352	14.186
5/16	13.548	14.607
3/8	13.744	15.033
7/16	13.941	15.466
1/2	14.137	15.904
9/16	14.334	16.349
5/8	14.530	16.800
11/16	14.726	17.257
3/4	14.923	17.721
13/16	15.119	18.190
7/8	15.315	18.665
15/16	15.512	19.147
5.	15.708	19.635
1/16	15.904	20.129
1/8	16.101	20.629
3/16	16.297	21.135
1/4	16.493	21.648
5/16	16.690	22.166
3/8	16.886	22.691
7/16	17.082	23.221
1/2	17.279	23.758
9/16	17.475	24.301
5/8	17.671	24.850
11/16	17.868	25.406
3/4	18.064	25.967
13/16	18.261	26.535
7/8	18.457	27.109
15/16	18.653	27.688
6.	18.850	28.274

Diam.	Circum.	Area.
6 1/8	19.242	29.465
1/4	19.635	30.680
3/8	20.028	31 919
1/2	20.420	33.183
5/8	20.813	34.472
3/4	21.206	35.785
7/8	21.598	37.122
7.	21.991	38.485
1/8	22.384	39.871
1/4	22.776	41.282
3/8	23.169	42.718
1/2	23.562	44.179
5/8	23.955	45.664
3/4	24.347	47.173
7/8	24.740	48.707
8.	25.133	50.265
1/8	25.525	51.849
1/4	25.918	53.456
3/8	26.311	55.088
1/2	26.704	56.745
5/8	27.096	58.426
3/4	27.489	60.132
7/8	27.882	61.862
9.	28.274	63.617
1/8	28.667	65.397
1/4	29.060	67.201
3/8	29.452	69.029
1/2	29.845	70.882
5/8	30.238	72.760
3/4	30.631	74.662
7/8	31.023	76.589
10.	31.416	78.540
1/8	31.809	80.516
1/4	32.201	82.516
3/8	32.594	84.541
1/2	32.987	86.590
5/8	33.379	88.664
3/4	33.772	90.763
7/8	34.165	92.886
11.	34.558	95.033
1/8	34.950	97.205
1/4	35.343	99.402
3/8	35.736	101.62
1/2	36.128	103.87
5/8	36.521	106.14
3/4	36.914	108.43
7/8	37.306	110.75
12.	37.699	113.10
1/8	38.092	115.47
1/4	38.485	117.86
3/8	38.877	120.28
1/2	39.270	122.72
5/8	39.663	125.19
3/4	40.055	127.68
7/8	40.448	130.19
13.	40.841	132.73
1/8	41.233	135 30
1/4	41.626	137.89
3/8	42.019	140.50
1/2	42.412	143.14

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
135/8	42.804	145.80	**21**7/8	68.722	375.83	**30**1/8	94.640	712.76
3/4	43.197	148.49	**22.**	69.115	380.13	1/4	95.033	718.69
7/8	43.590	151.20	1/8	69.508	384.46	3/8	95.426	724.64
14.	43.982	153.94	1/4	69.900	388.82	1/2	95.819	730.62
1/8	44.375	156.70	3/8	70.293	393.20	5/8	96.211	736.62
1/4	44.768	159.48	1/2	70.686	397.61	3/4	96.604	742.64
3/8	45.160	162.30	5/8	71.079	402.04	7/8	96.997	748.69
1/2	45.553	165.13	3/4	71.471	406.49	**31.**	97.389	754.77
5/8	45.946	167.99	7/8	71.864	410.97	1/8	97.782	760.87
3/4	46.338	170.87	**23.**	72.257	415.48	1/4	98.175	766.99
7/8	46.731	173.78	1/8	72.649	420.00	3/8	98.567	773.14
15.	47.124	176.71	1/4	73.042	424.56	1/2	98.960	779.31
1/8	47.517	179.67	3/8	73.435	429.13	5/8	99.353	785.51
1/4	47.909	182.65	1/2	73.827	433.74	3/4	99.746	791.73
3/8	48.302	185.66	5/8	74.220	438.36	7/8	100.138	797.98
1/2	48.695	188.69	3/4	74.613	443.01	**32.**	100.531	804.25
5/8	49.087	191.75	7/8	75.006	447.69	1/8	100.924	810.54
3/4	49.480	194.83	**24.**	75.398	452.39	1/4	101.316	816.86
7/8	49.873	197.93	1/8	75.791	457.11	3/8	101.709	823.21
16.	50.265	201.06	1/4	76.184	461.86	1/2	102.102	829.58
1/8	50.658	204.22	3/8	76.576	466.64	5/8	102.494	835.97
1/4	51.051	207.39	1/2	76.969	471.44	3/4	102.887	842.39
3/8	51.414	210.60	5/8	77.362	476.26	7/8	103.280	848.83
1/2	51.836	213.82	3/4	77.754	481.11	**33.**	103.673	855.30
5/8	52.229	217.08	7/8	78.147	485.98	1/8	104.065	861.79
3/4	52.622	220.35	**25.**	78.540	490.87	1/4	104.458	868.31
7/8	53.014	223.65	1/8	78.933	495.79	3/8	104.851	874.85
17.	53.407	226.98	1/4	79.325	500.74	1/2	105.243	881.41
1/8	53.800	230.33	3/8	79.718	505.71	5/8	105.636	888.00
1/4	54.192	233.71	1/2	80.111	510.71	3/4	106.029	894.62
3/8	54.585	237.10	5/8	80.503	515.72	7/8	106.421	901.26
1/2	54.978	240.53	3/4	80.896	520.77	**34.**	106.814	907.92
5/8	55.371	243.98	7/8	81.289	525.84	1/8	107.207	914.61
3/4	55.763	247.45	**26.**	81.681	530.93	1/4	107.600	921.32
7/8	56.156	250.95	1/8	82.074	536.05	3/8	107.992	928.06
18.	56.549	254.47	1/4	82.467	541.19	1/2	108.385	934.82
1/8	56.941	258.02	3/8	82.860	546.35	5/8	108.778	941.61
1/4	57.334	261.59	1/2	83.252	551.55	3/4	109.170	948.42
3/8	57.727	265.18	5/8	83.645	556.76	7/8	109.563	955.25
1/2	58.119	268.80	3/4	84.038	562.00	**35.**	109.956	962.11
5/8	58.512	272.45	7/8	84.430	567.27	1/8	110.348	969.00
3/4	58.905	276.12	**27.**	84.823	572.56	1/4	110.741	975.91
7/8	59.298	279.81	1/8	85.216	577.87	3/8	111.134	982.84
19.	59.690	283.53	1/4	85.608	583.21	1/2	111.527	989.80
1/8	60.083	287.27	3/8	86.001	588.57	5/8	111.919	996.78
1/4	60.476	291.04	1/2	86.394	593.96	3/4	112.312	1003.8
3/8	60.868	294.83	5/8	86.786	599.37	7/8	112.705	1010.8
1/2	61.261	298.65	3/4	87.179	604.81	**36.**	113.097	1017.9
5/8	61.654	302.49	7/8	87.572	610.27	1/8	113.490	1025.0
3/4	62.046	305.35	**28.**	87.965	615.75	1/4	113.883	1032.1
7/8	62.439	310.24	1/8	88.357	621.26	3/8	114.275	1039.2
20.	62.832	314.16	1/4	88.750	626.80	1/2	114.668	1046.3
1/8	63.225	318.10	3/8	89.143	632.36	5/8	115.061	1053.5
1/4	63.617	322.06	1/2	89.535	637.94	3/4	115.454	1060.7
3/8	64.010	326.05	5/8	89.928	643.55	7/8	115.846	1068.0
1/2	64.403	330.06	3/4	90.321	649.18	**37.**	116.239	1075.2
5/8	64.795	334.10	7/8	90.713	654.84	1/8	116.632	1082.5
3/4	65.188	338.16	**29.**	91.106	660.52	1/4	117.024	1089.8
7/8	65.581	342.25	1/8	91.499	666.23	3/8	117.417	1097.1
21.	65.973	346.36	1/4	91.892	671.96	1/2	117.810	1104.5
1/8	66.366	350.50	3/8	92.284	677.71	5/8	118.202	1111.8
1/4	66.759	354.66	1/2	92.677	683.49	3/4	118.596	1119.2
3/8	67.152	358.84	5/8	93.070	689.30	7/8	118.988	1126.7
1/2	67.544	363.05	3/4	93.462	695.13	**38.**	119.381	1134.1
5/8	67.937	367.28	7/8	93.855	700.98	1/8	119.773	1141.6
3/4	68.330	371.54	**30.**	94.248	706.86	1/4	120.166	1149.1

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
38 3/8	120.559	1156.6	**46** 5/8	146.477	1707.4	**54** 7/8	172.395	2365.0
1/2	120.951	1164.2	3/4	146.869	1716.5	**55.**	172.788	2375.8
5/8	121.344	1171.7	7/8	147.262	1725.7	1/8	173.180	2386.6
3/4	121.737	1179.3	**47.**	147.655	1734.9	1/4	173.573	2397.5
7/8	122.129	1186.9	1/8	148.048	1744.2	3/8	173.966	2408.3
39.	122.522	1194.6	1/4	148.440	1753.5	1/2	174.358	2419.2
1/8	122.915	1202.3	3/8	148.833	1762.7	5/8	174.751	2430.1
1/4	123.308	1210.0	1/2	149.226	1772.1	3/4	175.144	2441.1
3/8	123.700	1217.7	5/8	149.618	1781.4	7/8	175.536	2452.0
1/2	124.093	1225.4	3/4	150.011	1790.8	**56.**	175.929	2463.0
5/8	124.486	1233.2	7/8	150.404	1800.1	1/8	176.322	2474.0
3/4	124.878	1241.0	**48.**	150.796	1809.6	1/4	176.715	2485.0
7/8	125.271	1248.8	1/8	151.189	1819.0	3/8	177.107	2496.1
40.	125.664	1256.6	1/4	151.582	1828.5	1/2	177.500	2507.2
1/8	126.056	1264.5	3/8	151.975	1837.9	5/8	177.893	2518.3
1/4	126.449	1272.4	1/2	152.367	1847.5	3/4	178.285	2529.4
3/8	126.842	1280.3	5/8	152.760	1857.0	7/8	178.678	2540.6
1/2	127.235	1288.2	3/4	153.153	1866.5	**57.**	179.071	2551.8
5/8	127.627	1296.2	7/8	153.545	1876.1	1/8	179.463	2563.0
3/4	128.020	1304.2	**49.**	153.938	1885.7	1/4	179.856	2574.2
7/8	128.413	1312.2	1/8	154.331	1895.4	3/8	180.249	2585.4
41.	128.805	1320.3	1/4	154.723	1905.0	1/2	180.642	2596.7
1/8	129.198	1328.3	3/8	155.116	1914.7	5/8	181.034	2608.0
1/4	129.591	1336.4	1/2	155.509	1924.4	3/4	181.427	2619.4
3/8	129.983	1344.5	5/8	155.902	1934.2	7/8	181.820	2630.7
1/2	130.376	1352.7	3/4	156.294	1943.9	**58.**	182.212	2642.1
5/8	130.769	1360.8	7/8	156.687	1953.7	1/8	182.605	2653.5
3/4	131.161	1369.0	**50.**	157.080	1963.5	1/4	182.998	2664.9
7/8	131.554	1377.2	1/8	157.472	1973.3	3/8	183.390	2676.4
42.	131.947	1385.4	1/4	157.865	1983.2	1/2	183.783	2687.8
1/8	132.340	1393.7	3/8	158.258	1993.1	5/8	184.176	2699.3
1/4	132.732	1402.0	1/2	158.650	2003.0	3/4	184.569	2710.9
3/8	133.125	1410.3	5/8	159.043	2012.9	7/8	184.961	2722.4
1/2	133.518	1418.6	3/4	159.436	2022.8	**59.**	185.354	2734.0
5/8	133.910	1427.0	7/8	159.829	2032.8	1/8	185.747	2745.6
3/4	134.303	1435.4	**51.**	160.221	2042.8	1/4	186.139	2757.2
7/8	134.696	1443.8	1/8	160.614	2052.8	3/8	186.532	2768.8
43.	135.088	1452.2	1/4	161.007	2062.9	1/2	186.925	2780.5
1/8	135.481	1460.7	3/8	161.399	2073.0	5/8	187.317	2792.2
1/4	135.874	1469.1	1/2	161.792	2083.1	3/4	187.710	2803.9
3/8	136.267	1477.6	5/8	162.185	2093.2	7/8	188.103	2815.7
1/2	136.659	1486.2	3/4	162.577	2103.3	**60.**	188.496	2827.4
5/8	137.052	1494.7	7/8	162.970	2113.5	1/8	188.888	2839.2
3/4	137.445	1503.3	**52.**	163.363	2123.7	1/4	189.281	2851.0
7/8	137.837	1511.9	1/8	163.756	2133.9	3/8	189.674	2862.9
44.	138.230	1520.5	1/4	164.148	2144.2	1/2	190.066	2874.8
1/8	138.623	1529.2	3/8	164.541	2154.5	5/8	190.459	2886.6
1/4	139.015	1537.9	1/2	164.934	2164.8	3/4	190.852	2898.6
3/8	139.408	1546.6	5/8	165.326	2175.1	7/8	191.244	2910.5
1/2	139.801	1555.3	3/4	165.719	2185.4	**61.**	191.637	2922.5
5/8	140.194	1564.0	7/8	166.112	2195.8	1/8	192.030	2934.5
3/4	140.586	1572.8	**53.**	166.504	2206.2	1/4	192.423	2946.5
7/8	140.979	1581.6	1/8	166.897	2216.6	3/8	192.815	2958.5
45.	141.372	1590.4	1/4	167.290	2227.0	1/2	193.208	2970.6
1/8	141.764	1599.3	3/8	167.683	2237.5	5/8	193.601	2982.7
1/4	142.157	1608.2	1/2	168.075	2248.0	3/4	193.993	2994.8
3/8	142.550	1617.0	5/8	168.468	2258.5	7/8	194.386	3006.9
1/2	142.942	1626.0	3/4	168.861	2269.1	**62.**	194.779	3019.1
5/8	143.335	1634.9	7/8	169.253	2279.6	1/8	195.171	3031.3
3/4	143.728	1643.9	**54.**	169.646	2290.2	1/4	195.564	3043.5
7/8	144.121	1652.9	1/8	170.039	2300.8	3/8	195.957	3055.7
46.	144.513	1661.9	1/4	170.431	2311.5	1/2	196.350	3068.0
1/8	144.906	1670.9	3/8	170.824	2322.1	5/8	196.742	3080.3
1/4	145.299	1680.0	1/2	171.217	2332.8	3/4	197.135	3092.6
3/8	145.691	1689.1	5/8	171.609	2343.5	7/8	197.528	3104.9
1/2	146.084	1698.2	3/4	172.002	2354.3	**63.**	197.920	3117.2

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
631/8	198.313	3129.6	**71**3/8	224.231	4001.1	**79**5/8	250.149	4979.5
1/4	198.706	3142.0	1/2	224.624	4015.2	3/4	250.542	4995.2
3/8	199.098	3154.5	5/8	225.017	4029.2	7/8	250.935	5010.9
1/2	199.491	3166.9	3/4	225.409	4043.3	**80.**	251.327	5026.5
5/8	199.884	3179.4	7/8	225.802	4057.4	1/8	251.720	5042.3
3/4	200.277	3191.9	**72.**	226.195	4071.5	1/4	252.113	5058.0
7/8	200.669	3204.4	1/8	226.587	4085.7	3/8	252.506	5073.8
64.	201.062	3217.0	1/4	226.980	4099.8	1/2	252.898	5089.6
1/8	201.455	3229.6	3/8	227.373	4114.0	5/8	253.291	5105.4
1/4	201.847	3242.2	1/2	227.765	4128.2	3/4	253.684	5121.2
3/8	202.240	3254.8	5/8	228.158	4142.5	7/8	254.076	5137.1
1/2	202.633	3267.5	3/4	228.551	4156.8	**81.**	254.469	5153.0
5/8	203.025	3280.1	7/8	228.944	4171.1	1/8	254.862	5168.9
3/4	203.418	3292.8	**73.**	229.336	4185.4	1/4	255.254	5184.9
7/8	203.811	3305.6	1/8	229.729	4199.7	3/8	255.647	5200.8
65.	204.204	3318.3	1/4	230.122	4214.1	1/2	256.040	5216.8
1/8	204.596	3331.1	3/8	230.514	4228.5	5/8	256.433	5232.8
1/4	204.989	3343.9	1/2	230.907	4242.9	3/4	256.825	5248.9
3/8	205.382	3356.7	5/8	231.300	4257.4	7/8	257.218	5264.9
1/2	205.774	3369.6	3/4	231.692	4271.8	**82.**	257.611	5281.0
5/8	206.167	3382.4	7/8	232.085	4286.3	1/8	258.003	5297.1
3/4	206.560	3395.3	**74.**	232.478	4300.8	1/4	258.396	5313.3
7/8	206.952	3408.2	1/8	232.871	4315.4	3/8	258.789	5329.4
66.	207.345	3421.2	1/4	233.263	4329.9	1/2	259.181	5345.6
1/8	207.738	3434.2	3/8	233.656	4344.5	5/8	259.574	5361.8
1/4	208.131	3447.2	1/2	234.049	4359.2	3/4	259.967	5378.1
3/8	208.523	3460.2	5/8	234.441	4373.8	7/8	260.359	5394.3
1/2	208.916	3473.2	3/4	234.834	4388.5	**83.**	260.752	5410.6
5/8	209.309	3486.3	7/8	235.227	4403.1	1/8	261.145	5426.9
3/4	209.701	3499.4	**75.**	235.619	4417.9	1/4	261.538	5443.3
7/8	210.094	3512.5	1/8	236.012	4432.6	3/8	261.930	5459.6
67.	210.487	3525.7	1/4	236.405	4447.4	1/2	262.323	5476.0
1/8	210.879	3538.8	3/8	236.798	4462.2	5/8	262.716	5492.4
1/4	211.272	3552.0	1/2	237.190	4477.0	3/4	263.108	5508.8
3/8	211.665	3565.2	5/8	237.583	4491.8	7/8	263.501	5525.3
1/2	212.058	3578.5	3/4	237.976	4506.7	**84.**	263.894	5541.8
5/8	212.450	3591.7	7/8	238.368	4521.5	1/8	264.286	5558.3
3/4	212.843	3605.0	**76.**	238.761	4536.5	1/4	264.679	5574.8
7/8	213.236	3618.3	1/8	239.154	4551.4	3/8	265.072	5591.4
68.	213.628	3631.7	1/4	239.546	4566.4	1/2	265.465	5607.9
1/8	214.021	3645.0	3/8	239.939	4581.3	5/8	265.857	5624.5
1/4	214.414	3658.4	1/2	240.332	4596.3	3/4	266.250	5641.2
3/8	214.806	3671.8	5/8	240.725	4611.4	7/8	266.643	5657.8
1/2	215.199	3685.3	3/4	241.117	4626.4	**85.**	267.035	5674.5
5/8	215.592	3698.7	7/8	241.510	4641.5	1/8	267.428	5691.2
3/4	215.984	3712.2	**77.**	241.903	4656.6	1/4	267.821	5707.9
7/8	216.377	3725.7	1/8	242.295	4671.8	3/8	268.213	5724.7
69.	216.770	3739.3	1/4	242.688	4686.9	1/2	268.606	5741.5
1/8	217.163	3752.8	3/8	243.081	4702.1	5/8	268.999	5758.3
1/4	217.555	3766.4	1/2	243.473	4717.3	3/4	269.392	5775.1
3/8	217.948	3780.0	5/8	243.866	4732.5	7/8	269.784	5791.9
1/2	218.341	3793.7	3/4	244.259	4747.8	**86.**	270.177	5808.8
5/8	218.733	3807.3	7/8	244.652	4763.1	1/8	270.570	5825.7
3/4	219.126	3821.0	**78.**	245.044	4778.4	1/4	270.962	5842.6
7/8	219.519	3834.7	1/8	245.437	4793.7	3/8	271.355	5859.6
70.	219.911	3848.5	1/4	245.830	4809.0	1/2	271.748	5876.5
1/8	220.304	3862.2	3/8	246.222	4824.4	5/8	272.140	5893.5
1/4	220.697	3876.0	1/2	246.615	4839.8	3/4	272.533	5910.6
3/8	221.090	3889.8	5/8	247.008	4855.2	7/8	272.926	5927.6
1/2	221.482	3903.6	3/4	247.400	4870.7	**87.**	273.319	5944.7
5/8	221.875	3917.5	7/8	247.793	4886.2	1/8	273.711	5961.8
3/4	222.268	3931.4	**79.**	248.186	4901.7	1/4	274.104	5978.9
7/8	222.660	3945.3	1/8	248.579	4917.2	3/8	274.497	5996.0
71.	223.053	3959.2	1/4	248.971	4932.7	1/2	274.889	6013.2
1/8	223.446	3973.1	3/8	249.364	4948.3	5/8	275.282	6030.4
1/4	223.838	3987.1	1/2	249.757	4963.9	3/4	275.675	6047.6

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
87 7/8	276.067	6064.9	95 7/8	301.200	7219.4	130	408.41	13273.23
88.	276.460	6082.1	96.	301.593	7238.2	131	411.55	13478.22
1/8	276.853	6099.4	1/8	301.986	7257.1	132	414.69	13684.78
1/4	277.246	6116.7	1/4	302.378	7276.0	133	417.83	13892.91
3/8	277.638	6134.1	3/8	302.771	7294.9	134	420.97	14102.61
1/2	278.031	6151.4	1/2	303.164	7313.8	135	424.12	14313.88
5/8	278.424	6168.8	5/8	303.556	7332.8	136	427.26	14526.72
3/4	278.816	6186.2	3/4	303.949	7351.8	137	430.40	14741.14
7/8	279.209	6203.7	7/8	304.342	7370.8	138	433.54	14957.12
89.	279.602	6221.1	97.	304.734	7389.8	139	436.68	15174.68
1/8	279.994	6238.6	1/8	305.127	7408.9	140	439.82	15393.80
1/4	280.387	6256.1	1/4	305.520	7428.0	141	442.96	15614.50
3/8	280.780	6273.7	3/8	305.913	7447.1	142	446.11	15836.77
1/2	281.173	6291.2	1/2	306.305	7466.2	143	449.25	16060.61
5/8	281.565	6308.8	5/8	306.698	7485.3	144	452.39	16286.02
3/4	281.958	6326.4	3/4	307.091	7504.5	145	455.53	16513.00
7/8	282.351	6344.1	7/8	307.483	7523.7	146	458.67	16741.55
90.	282.743	6361.7	98.	307.876	7543.0	147	461.81	16971.67
1/8	283.136	6379.4	1/8	308.269	7562.2	148	464.96	17203.36
1/4	283.529	6397.1	1/4	308.661	7581.5	149	468.10	17436.62
3/8	283.921	6414.9	3/8	309.054	7600.8	150	471.24	17671.46
1/2	284.314	6432.6	1/2	309.447	7620.1	151	474.38	17907.86
5/8	284.707	6450.4	5/8	309.840	7639.5	152	477.52	18145.84
3/4	285.100	6468.2	3/4	310.232	7658.9	153	480.66	18385.39
7/8	285.492	6486.0	7/8	310.625	7678.3	154	483.81	18626.50
91.	285.885	6503.9	99.	311.018	7697.7	155	486.95	18869.19
1/8	286.278	6521.8	1/8	311.410	7717.1	156	490.09	19113.45
1/4	286.670	6539.7	1/4	311.803	7736.6	157	493.23	19359.28
3/8	287.063	6557.6	3/8	312.196	7756.1	158	496.37	19606.68
1/2	287.456	6575.5	1/2	312.588	7775.6	159	499.51	19855.65
5/8	287.848	6593.5	5/8	312.981	7795.2	160	502.65	20106.19
3/4	288.241	6611.5	3/4	313.374	7814.8	161	505.80	20358.31
7/8	288.634	6629.6	7/8	313.767	7834.4	162	508.94	20611.99
92.	289.027	6647.6	100	314.159	7854.0	163	512.08	20867.24
1/8	289.419	6665.7	101	317.30	8011.85	164	515.22	21124.07
1/4	289.812	6683.8	102	320.44	8171.28	165	518.36	21382.46
3/8	290.205	6701.9	103	323.58	8332.29	166	521.50	21642.43
1/2	290.597	6720.1	104	326.73	8494.87	167	524.65	21903.97
5/8	290.990	6738.2	105	329.87	8659.01	168	527.79	22167.08
3/4	291.383	6756.4	106	333.01	8824.73	169	530.93	22431.76
7/8	291.775	6774.7	107	336.15	8992.02	170	534.07	22698.01
93.	292.168	6792.9	108	339.29	9160.88	171	537.21	22965.83
1/8	292.561	6811.2	109	342.43	9331.32	172	540.35	23235.22
1/4	292.954	6829.5	110	345.58	9503.32	173	543.50	23506.18
3/8	293.346	6847.8	111	343.72	9676.89	174	546.64	23778.71
1/2	293.739	6866.1	112	351.86	9852.03	175	549.78	24052.82
5/8	294.132	6884.5	113	355.00	10028.75	176	552.92	24328.49
3/4	294.524	6902.9	114	358.14	10207.03	177	556.06	24605.74
7/8	294.917	6921.3	115	361.28	10386.89	178	559.20	24884.56
94.	295.310	6939.8	116	364.42	10568.32	179	562.35	25164.94
1/8	295.702	6958.2	117	367.57	10751.32	180	565.49	25446.90
1/4	296.095	6976.7	118	370.71	10935.88	181	568.63	25730.43
3/8	296.488	6995.3	119	373.85	11122.02	182	571.77	26015.53
1/2	296.881	7013.8	120	376.99	11309.73	183	574.91	26302.20
5/8	297.273	7032.4	121	380.13	11499.01	184	578.05	26590.44
3/4	297.666	7051.0	122	383.27	11689.87	185	581.19	26880.25
7/8	298.059	7069.6	123	386.42	11882.29	186	584.34	27171.63
95.	298.451	7088.2	124	389.56	12076.28	187	587.48	27464.59
1/8	298.844	7106.9	125	392.70	12271.85	188	590.62	27759.11
1/4	299.237	7125.6	126	395.84	12468.98	189	593.76	28055.21
3/8	299.629	7144.3	127	398.98	12667.69	190	596.90	28352.87
1/2	300.022	7163.0	128	402.12	12867.96	191	600.04	28652.11
5/8	300.415	7181.8	129	405.27	13069.81	192	603.19	28952.92
3/4	300.807	7200.6						

WEIGHT OF RODS, BARS, PLATES, TUBES, AND SPHERES OF DIFFERENT MATERIALS.

Notation: b = breadth, t = thickness, s = side of square, D = external diameter, d = internal diameter, all in inches.

Sectional areas: of square bars = s^2; of flat bars = bt; of round rods = $0.7854\ D^2$; of tubes = $0.7854\ (D^2 - d^2) = 3.1416\ (Dt - t^2)$.

Volume of 1 foot in length: of square bars = $12s^2$; of flat bars = $12bt$; of round bars = $9.4248D^2$; of tubes = $9.4248\ (D^2 - d^2) = 37.699\ (Dt - t^2)$, in cu. in.

Weight per foot length = volume × weight per cubic inch of material. Weight of a sphere = diam.^{3} × 0.5236 × weight per cubic inch.

Material.	Specific Gravity.	Weight per Cubic Foot, Lbs.	Weight of Plates 1 Inch Thick per Sq. Ft., Lbs.	Weight of Square Bars per Foot Length, Lbs.	Weight of Flat Bars per Foot Length, Lbs.	Weight per Cubic Inch, Lbs.	Relative Weights. Wrought Iron = 1	Weight of Round Rod per Foot Length, Lbs.	Weight of Spheres or Balls, Lbs.
				s^2 ×	bt ×			D^2 ×	D^3 ×
Cast iron...........	7.218	450.	37.5	3 1/8	3 1/8	.2604	15–16	2.454	.1363
Wrought iron......	7.7	480.	40.	3 1/3	3 1/3	.2779	1.	2.618	.1455
Steel...............	7.854	489.6	40.8	3.4	3.4	.2833	1.02	2.670	.1484
Copper & Bronze (copper and tin)	8.855	552.	46.	3.833	3.833	.3195	1.15	3.011	.1673
Brass {65 copper, 35 Zinc...}	8.393	523.2	43.6	3.633	3.633	.3029	1.09	2.854	.1586
Lead...............	11.38	709.6	59.1	4.93	4.93	.4106	1.48	3.870	.2150
Aluminum.........	2.67	166.5	13.9	1.16	1.16	.0963	0.347	0.908	.0504
Glass..............	2.62	163.4	13.6	1.13	1.13	.0945	0.34	0.891	.0495
Pine wood, dry....	0.481	30.0	2.5	0.21	0.21	.0174	1–16	0.164	.0091

Weight per cylindrical in., 1 in. long, = coefficient of D^2 in next to last col. ÷ 12.

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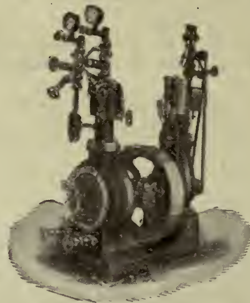

Barge Office, New York, showing the U. S. Revenue Cutters, "CALUMET", "HUDSON" and "MACKINAC" each containing a Roberts Boiler. The following U. S. Revenue Cutters are also equipped with Roberts Boilers: "WISSAHICKON", "ARCATA", "ALERT", "WINNISSIMMET", "SCOUT", "GUARD", "TYBEE", "PENROSE" etc.

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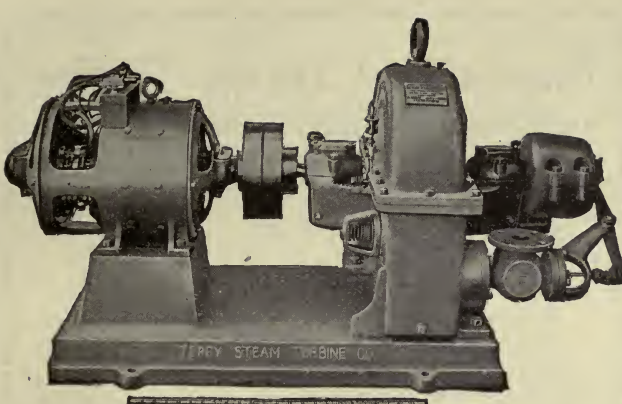

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